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FINAL REPORT

COOPERATIVE AGREEMENT

INT-89419-RJVA

CANADA MASS-FIRE AND DYNAMICS EXPERIMENTS FOR 1989: CONTRIBUTIONS OF THE UNIVERSITY OF IOWA GROUP IN THE AREAS OF SENSOR AND ARRAY EVALUATION, SURFACE AND NEAR SURFACE FIRE DYNAMICS, WIND FIELDS, DATA INTEGRATION USING A GIS, AND FLOW FIELD VISUALIZATION

prepared by

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Associate Professor, Department of Civil and Environmental Engineering
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University of Iowa, Iowa City, Iowa 52242

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EXECUTIVE SUMMARY

The Hill Township Prescribed Fire study was an interdisciplinary, interagency, mass fire experiment carried out in the summer of 1989 in Northern Ontario, Canada. The University of Iowa's (UI) role in the project involved: (a) the deployment and preliminary data analysis of two turbulence sensor arrays and a fire spread array following a specified design; (b) the deployment and analysis of additional wind and thermal sensor systems designed by the UI and intended to characterize the overall wind field in the fire and the testing of several sensor designs; and (c) the integration of wind field data, terrain data and other related information using a GIS system.

The detailed findings and basic data collected in this study, as well as the presentation of integrated information in the form of text, figures, data files, image files, and computer generated video animation of the in-fire and perimeter wind fields are presented in three appendices incorporated into this report. In total the UI deployed some 400 sensors and collected approximately 5,500,000 observations during the course of the fire. The overall findings demonstrate the feasibility of an integrated field and data analysis strategy and involve a series of specific recommendations regarding the manner in which such studies might be carried out in the future. The overall goal is to contribute to the development of a standardized methodology which could be utilized to measure fundamental field parameters, characterize basic fire processes, and model overall fire dynamics in medium to larger scale mass fires.

INTRODUCTION

The Hill Township Prescribed Fire study was an interdisciplinary, interagency, mass fire experiment carried out in the summer of 1989 in Northern Ontario, Canada. The project involved participants from Forestry Canada (FC), the United States Forest Service of the USDA (USFS), the Center for Fire Research of the National Institute of Standards and Technology (NIST), the Department of Geography of the University of Iowa (UI), Pacific-Sierra Research Corporation (PSRC), and the University of Washington (UW).

The general goals of the overall experiment were summarized in the report entitled "Plan of work for Canadian Mass-Fire and Fire Dynamics Experiments for 1989" prepared by Richard Hartley, Darold Ward, James Quintiere and Brian Stocks and the overview report entitled "Canada Mass Fire Experiment, 1989" NISTIR Report 4444 by James Quintiere. They will not be repeated here. The University of Iowa's role in this project involved three distinct activities: (a) the deployment and preliminary data analysis of two turbulence sensor arrays and a fire spread array following a design provided by PSRC; (b) the deployment and preliminary data analysis of additional wind and thermal sensor systems designed by the UI and intended to provide the overall wind field in the fire as well as the testing of several sensor designs; and (c) the integration of the wind field data, terrain data and other related information using a GIS system. These goals were articulated in more detail in the plan of work cited above as well as in the study plans provided in the preparation and execution of the original agreements.

The results of the first set of activities, designated as (a) above, were completed and presented in the report entitled: "Preliminary Results From the Hill Township Prescribed Burn" and are incorporated here as part of Appendix I. The results of activities grouped under (b) above were incorporated in the report entitled: "Progress Report on Cooperative Agreement INT-89419-RJVA" and are incorporated here as part of Appendix II. The results relating to the last general goal, that of integrating the wind field data, terrain data and other information using a GIS, item (c) above, are presented in Appendix III of this final report. Also, included in Appendix III are the summary data printouts, copies of the basic data terrain, wind and image files (in ASCII format) and copies of both the preliminary and final video presentations of the data.

The focus of the following discussion will be on making recommendations regarding the manner in which this data and similar data, which might be collected in future projects, would most effectively be collected and integrated. In particular, the emphasis of the following discussion will be upon the methods by which the wind field data and related terrain, temperature and fuel characteristics might be most effectively integrated using a GIS based system. As has already been noted, the details are provided in the three appendices.

FINAL SUMMARY REPORT AND RECOMMENDATIONS

INTRODUCTION

As indicated in the introduction, the following discussion will seek to provide a series of detailed recommendations, based on the findings of this study, regarding the conduct of similar studies in the future. These recommendations are grouped in a series of general recommendations regarding; the wind sensing systems, the temperature sensing systems, fuel characterization, basic terrain data requirements: and a series of specific series of recommendations with respect the use of a GIS to integrate the different data layers assembled during the course of such a study.

GENERAL RECOMMENDATIONS

The Wind Sensing Systems

With respect to the basic field instrumentation to measure the wind the following recommendations are made:

1) the use of thermal anemometers for in-fire measurements be discontinued (unless specific new thermal sensors with extremely short thermal compensation time become available);

2) ideally, the development and deployment of true, triaxial, anemometers with metal blades and associated heat capacities should be undertaken;

3) failing the availability of metal-bladed, triaxial systems, the use of already available metal cup anemometer units along with metal wind vane systems for characterization of horizontal wind fields should be utilized;

4) failing the availability of metal-bladed triaxial systems higher temperature, non-metallic, bladed systems may continue to be utilized to obtain vertical flux measurements;

5) the in-fire wind field monitoring systems and the perimeter wind field measurement systems should consist of identical instrumentation systems to minimize between sensor variability;

6) when carrying out a center fire ignition pattern the tower deployment pattern should consist of a center tower surrounding concentric rings of wind field monitoring towers radiating outward at either the cardinal or semi-cardinal points of the compass;

7) an outer ring of beyond-fire perimeter towers be deployed in

such a way that they too fall along the cardinal or semi-cardinal compass directions;

8) the alternative to recommendations 5,6, and 7 is a tower deployment pattern which would utilize a square grid pattern consisting of 4, 9, 16 or 25 towers. Such an alternative may be more appropriate for linear or complex ignition patterns which do not follow a center fire strategy.

9) whether recommendations 5,6,7 or 8 are utilized, equal spacing of the rings or grid is recommended to facilitate data integration;

10) standard height of measurement (first option of 10 meters) should be adopted throughout the grid;

11) synchronized sample rates and clocks be employed with frequency of sampling on the order of 2 to 5 seconds for general wind field data for fires in the 100 - 1000 hectare size range;

12) sample rates for both in-fire towers and perimeter towers beyond the immediate fire area should be the same;

13) an integrated ambient wind monitoring system using at least three wind monitoring towers should be included as part of the overall wind monitoring system. These should consist of at least one upwind system and one downwind system and a third tower located at right angles to the first up and downwind systems. These should all be well beyond the location of the perimeter towers and beyond the range of the immediate wind flow field alteration associated with the in-fire generated winds.

14) precise location information (both horizontal and vertical) should be obtained for the anemometers, preferably using a GPS system (or as a default, a careful ground survey).

15) the anemometer system should be operated for several days prior to the actual fire itself in order to enable the determination of the effect of terrain induced flow acceleration on the horizontal and vertical wind velocity measurements and the general perturbation pattern such flow accelerations will introduce into the general wind field mapping during the fire itself;

16) preferably the pre-fire wind field mapping should occur with the same prevailing wind direction as that which will be in effect during the fire itself in order to enable the compensation for the effect of ambient wind on the overall wind field active during the fire.

The Temperature Sensing Systems

With respect to the temperature measurement the use of a surface thermocouple grid surrounding the base of the anemometer towers in conjunction with a vertical array of thermocouples, as used in this experiment, has proven quite effective at providing near tower, localized fire spread rates and general thermal characteristics. When integrated with the local wind dynamic data from the adjacent tower the general character of the local fire and wind dynamics may be determined.

From the perspective of the goal of characterizing the overall thermal dynamics of the fire (ie. spread rates, energy release rates) the grid of surface temperature sensors surrounding each tower must be regarded as only indicators of local activity and the range of variability within the overall fire field. Indeed the role of such thermal ground sensor systems ought properly to be to serve as ground calibration points for remote sensing of the entire thermal field. This can be accomplished through the use of the remote (in this case helicopter mounted) infra-red (IR) scanner system such as that deployed by the FC during the course of the Hill fire. The rapid (1 second) scanning and digital imaging capacity of this system makes it very attractive for such an application. Crucial to the success of the use of a semi-stationary, airborne continuous (or near continuous), scanning IR system, however, is the need for adequate ground registry of the images being generated. This may be best accomplished through the use of carefully surveyed thermal targets. Ideally, these thermal reference points (such as charcoal burning pot systems) should be located immediately adjacent to the towers. At least three and preferably five of such thermal markers should be utilized in a fire. (Further advances on this technology are currently underway.) The exact location of these markers must be either surveyed into place or located via GPS technology.

Fuel Characterization

With respect to the fuel characterization, it is recommended that, wherever possible, a fuel triangle be established in the immediate vicinity of each tower, preferably centering on the ground thermocouple circle surrounding the base of each tower. The resulting ability to relate to fuel characteristics, to fuel consumption and to fire dynamics at each tower offers a critical capacity to determine local processes and in the broader terms enable better assessment of the spatial variability of the fire and the relationship between such variability and overall fire dynamics.

Basic Terrain Data

With respect to the basic terrain data the following recommendations are made:

1) given the lack of detailed topographic data for most fire sites it is essential that a pre-fire aerial survey be undertaken to provide the base information for the development of a detailed terrain map of the site;

2) the establishment of several carefully established control points for such a survey is critical for the success of such an effort;

3) a digital terrain map should be prepared, preferably in advance of the tower installation, for equipment locational purposes. Even more significantly this terrain map with control points (both vertical and horizontal) is crucial for the subsequent GIS data integration effort.

4) the digital terrain mapping is also central to the determination of flow acceleration processes associated with terrain effects. This will directly impact the success of isolation of the flow acceleration processes discussed in points (15 and (16) above.

SPECIFIC RECOMMENDATIONS WITH RESPECT TO THE GIS INTEGRATION OF DATA

The effective use of a GIS to provide additional spatial integration and more effective calculation of processes (such as fire spread rates or overall wind field dynamics) necessitates additional data and operational requirements above those indicated above for more conventional analysis efforts. With respect to the use of a GIS for modelling and analysis the following additional recommendations are made:

1) central to any effort to establish a GIS system is the develop of a detailed digital terrain database of extremely high quality. The acquisition of project specific, high resolution imagery from which a detailed base map may be prepared is fundamental to the overall success of the entire integration effort.

2) the establishment of known surface control points using GPS or similar high resolution locational methods to provide secure reference and registration points is also essential;

3) detailed fuel load mapping, where possible, would also greatly increase the ability to integrate the overall processes at work. This might be carried out with a combination of aerial photographic data, ground transects, and fuel triangles, and would result in a full spatial

mapping of the vegetation and fuel loading. This information could then be entered as a fully registered data layer in the GIS structure.

4) the precise location of the wind and temperature sensors and arrays must be registered on the base terrain map as well as on the vegetation data layer;

5) full synchronization (within 1 second) of the ground sensor temperature arrays with the IR imaging system must also be undertaken in order to enable not only spatial but also chronological interlocking of the ground and remote data sets;

6) full synchronization (within 1 second) of the wind sensor arrays with the IR imaging system must also be undertaken in order to enable full interlocking to be carried out;

7) the standardization of all sensors systems is critical to the success of a GIS based, fire-wide analysis of fire dynamics. Variation in sensor response times, sample rates, sensor elevations, etc., will greatly impede the GIS integration effort.

8) the use of data from non-standard sensors in the main instrumentation array should be undertaken with great caution. Data from dedicated anemometer systems, for example, intended to be part of a turbulence array system, ought not be incorporated in the general wind field data unless a standardized wind tower, consistent with the others in the main grid, is in close proximity in order to enable cross-calibration and a minimum cross-comparison to be carried out.

9) given the likelihood of multiple investigators being part of a fire project it is essential that all data intended for integration into the basic spatial data fields or layers constituting the GIS integration effort be provided in a standardized format (ie., ASCII files). Perhaps even more important is the necessity of a standardized digital base map for location of all sensors, sensor systems and data inputs to the overall modelling and analysis effort. The ability to correctly and consistently provide registration of data layers (such as vegetation, wind fields, thermal fields) is critically controlled by the success of this common registry effort. The need to provide all participants a detailed site base map that is ultimately digitally derived cannot be overemphasized.

10) the GIS system to be utilized, in order to enable effective intercomparison with other research efforts, should be a standardized system such as GRASS or ARCINFO. The system of choice by this research group (UI) is ARCINFO. Moreover, the consistent use of the same core GIS from project to project will further guarantee the success of fire to fire comparisons.

GENERAL CONCLUSIONS

The above recommendations represent the distillation of much of the experience gained in this project. The details are provided in the appendices. Many of the recommendations are already being applied in ongoing research efforts. These recommendations should provide the basis for the development of a standardized approach to: (1) the collection, integration, and analysis of surface and near surface fire date; and (2) in particular, advance our capacity to model and understand the internal fire and perimeter wind fields, thermal fluxes in and above the fire, fuel consumption and other critical dynamic fire data.

APPENDIX I

RESULTS OF THE HILL TOWNSHIP PRESCRIBED BURN:

OBJECTIVES A - D

OVERVIEW

The material presented here relates to objectives A - D outlined in the original research agreement as follows:

A. Purchase, prepare, and transport equipment identified in the study plan to and from the site(s).

B. Install and operate equipment in a cooperative effort with researchers from PSRC and the Station.

C. Obtain continuous wind and temperature data.

D. Reduce data to useable form.

The results of the above effort were originally presented in the report entitled: "Preliminary results from the Hill Township Prescribed Burn" prepared by the P.I. and submitted previously. The following materials incorporate the material from that report. They provide a general view of the deployment and utilization of the equipment, an evaluation of the performance of the instrumentation, and the data obtained.

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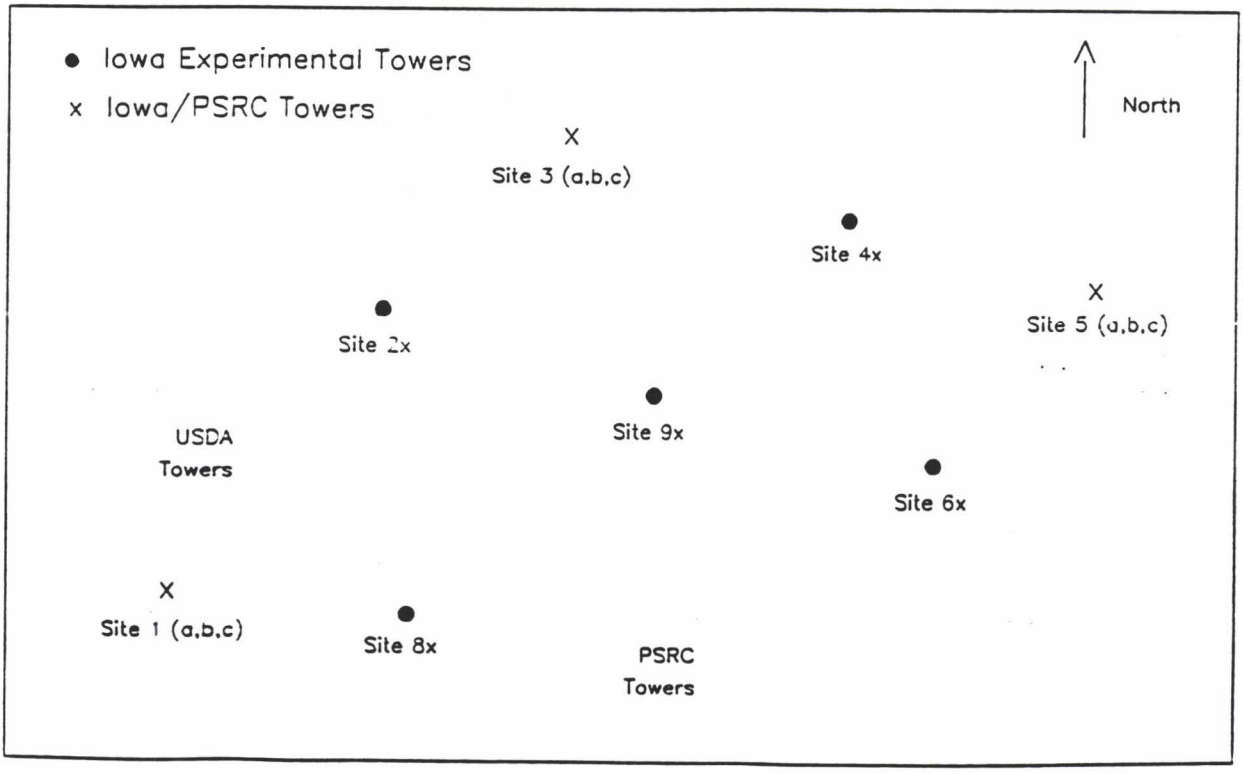
INTRODUCTION

The following report constitutes the results of the preliminary data dumping, calibration, primary analysis and structuring of the wind and temperature field measurements made by the University of Iowa as part of the overall Canadian Fire Project carried out in the summer of 1989 in Northern Ontario, Canada. The data presented here were collected on August 10, 1989 in the Hill Township Fire. The instrument selection and deployment design used to collect these particular data follows the design and deployment suggested by PSRC. The additional data collected independently of PSRC by the University of Iowa, and following Iowa's own design and deployment strategy, will be presented separately.

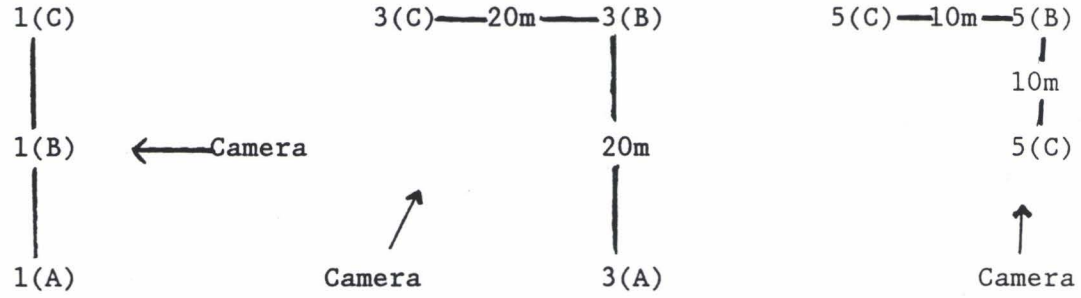
General Location of Equipment

The general location of the Iowa/PSRC towers which are the subject of this report are indicated in the diagram below by an X . Their position relative to Iowa's experimental towers is indicated by the closed circle symbols representing the Iowa experimental towers. The numbering scheme adopted encompasses both sets of towers.

RELATIVE LOCATION OF IOWA EXPERIMENTAL TOWERS, HILL TOWNSHIP FIRE



Site 1 is the spread array, the suffixes (A,B,C) indicate respective towers within the array with 1A being furthest downslope, and 1C furthest upslope. Site 3 and towers 3A, 3B and 3C are the 20 m apart turbulence array, and site 5 and towers 5A, 5B and 5C represents the 10 m apart turbulence array. In the case of both the turbulence arrays the (A) tower is the one closest to the location of the video system. The (B) tower is the one parallel to the (A) tower and the (C) tower is the one positioned at 90 degrees to the (A) and (B) towers.(See below)



A more detailed description of the spread and turbulence arrays designs should be provided in their component of the study plan.

Presentation of the Data

The data is provided on floppy disks following the guidelines provided in the next section (Data Format on Floppy Disks). A hard copy graphing of the data has also been included in the Compilation of Data section.

All times indicated are Eastern Standard Time. The times are correct within 5 seconds or better of EST (they were synchronized via direct radio time check with a central clock in Ottawa the morning of the fire. The synchronization between the loggers (manually set) remained within 2 seconds across the units we operated (sites 1, 3, 5 and the Iowa Experimental towers.

DISCUSSION OF THE DATA QUALITY

Since this document seeks to specifically provide data that may be shared with other members of the project the present discussion is not focussed upon a detailed analysis of the findings. Instead a review of the quality of the data seems more appropriate. This review should provide a useful guide to others as to the value and limitations of the data. This will be done by sensor type and also in terms of sensor integration with the logging systems.

Cup Anemometers

The cup anemometers were pulse counters which for the most part performed as designed. Several failed at some point during the fire (likely due to overheating by the fire). Such failures are clearly indicated in the graphed data and should present little confusion. The other point to be made is that given the sampling rate of a scan every 2 seconds some allowance must be made for integration effects. It must also be realized that the units are in effect averaging units and do not provide continuous or near instantaneous data (more on this later).

Direction Sensors

The direction sensors performed well although the signal tended to bounce a great deal. Moreover, they were sampled every 2 seconds, essentially instantaneously and so their response is somewhat different than that of the cup anemometers.

Cup Anemometers in the Arrays

The turbulence arrays sought to relate dynamic activity in a relatively small grid and hence simultaneous recording was a consideration. It should be kept in mind that the synchronization between loggers in the turbulence arrays was not better than 0.5 seconds (as requested they were NOT electronically synchronized) - hence simultaneous pulse counts were not obtained and correlation errors must be considered, particularly when the gap was only 10 or 20 m/s between towers and horizontal velocities were on the order of 10 - 15 m/s in the fire. Moreover, the sampling rate of one reading every 2 seconds must be kept in mind. The above considerations aside, as a general indicator of horizontal wind velocities the cups performed reasonably well, particularly on a larger fire scale where 0.5 second synchronization was quite acceptable.

Thermal Anemometers

The readings from the thermal anemometers was not included in this data set because the data is somewhat misleading. The thermal anemometers, mounted in a restrictive aluminum shield, were intended to only record vertical fluxes and hence compliment the horizontal cup data. Unfortunately the thermals proved incapable of compensating for the rapid temperature changes taking place in the flaming front and even in the smoldering phase their response is questionable. It simply is not possible to ascribe a level of reliability to these units when there is any rapid or moderately rapid thermal fluctuation. The time constant for the thermal compensation is 15 seconds while the velocity head response time is much faster (optimally on the order of 1 second). The

compensation errors are so large that the sensors read 0 or near 0 during the flaming front arrival, precisely when higher velocities are expected.

The following graphs from of the thermal anemometer data illustrates the point. In each case the thermal fails dramatically at the height of the fire and it's subsequent recovery can only be characterized as dubious. The data from Site c illustrates this - just when the temperatures rise the sensor fails.

The issue is further compounded be the effect of the shields. Post-fire wind tunnel testing of the shields (in an optimal low turbulence environment has shown that with a pure horizontal wind (no vertical component) the sensor will register the presence of a vertical wind upwards of 20% of the horizontal flow (ie. in a pure horizontal wind of 10 m/s with no vertical flow the thermal will register a false 2.5 m/s vertical flux. The actual winds measured in the fire (using other sensors) indicate real vertical fluxes of up to 5 m/s are common. The shields therefore indicated, even under moderate conditions, vertical fluxes on the order of 50% error relative to the actual values. The result is confusing and often contradictory data. The thermal anemometers at Site 5A and 5C (see graphs following) were not 15 m apart yet the readings they provide are not even near being in agreement.Moreover, these difficulties do not include the thermal compensation error discussed above. Finally, the above limitations are compounded by the inability of the thermals anemometers to indicate whether flow is up or down - a rather crucial item of data.

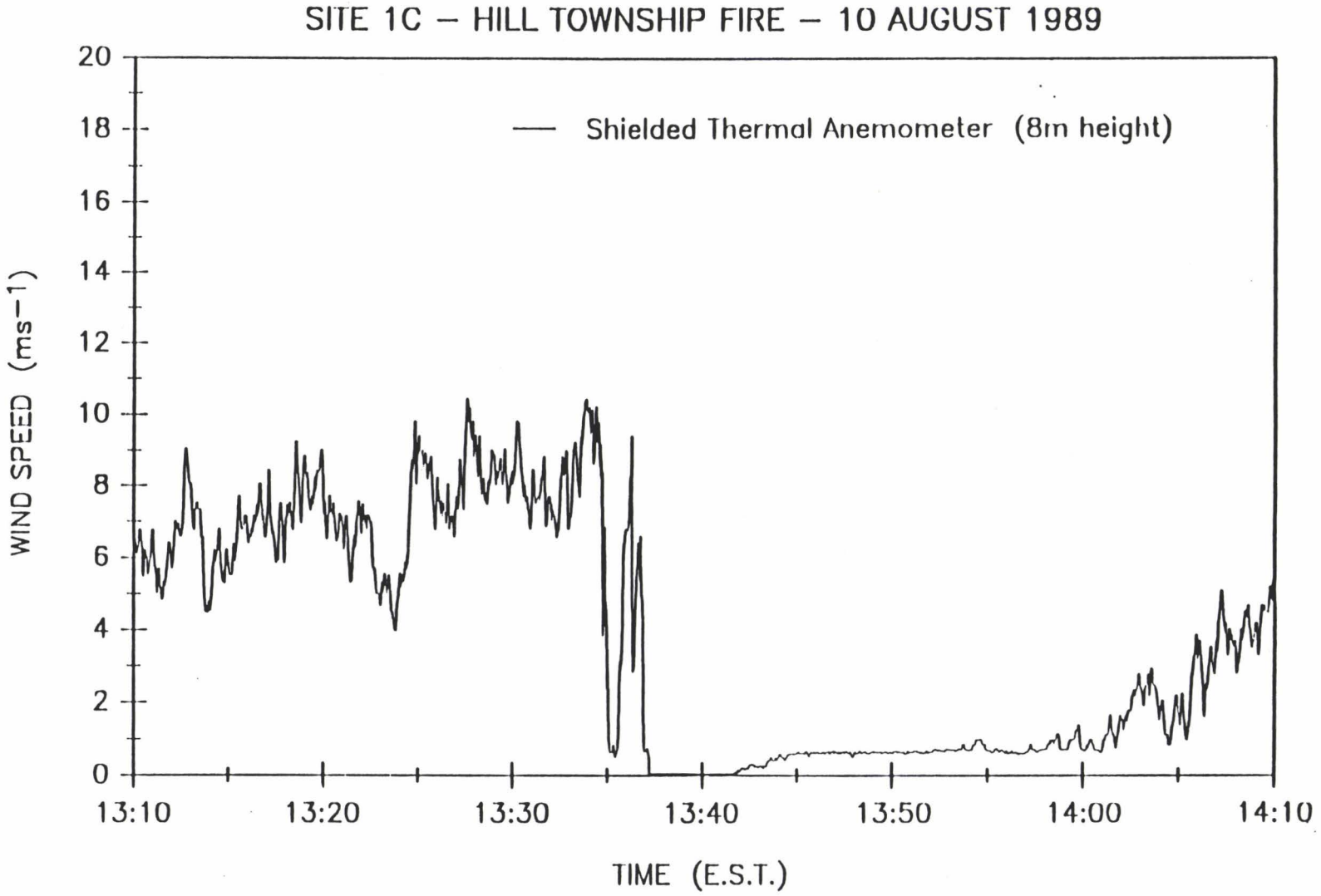
Given all of the above, it was felt that the thermal anemometer data would be misleading and should not be incorporated in such a general use data set. The use of such sensors in fire fields in the future is not recommended.

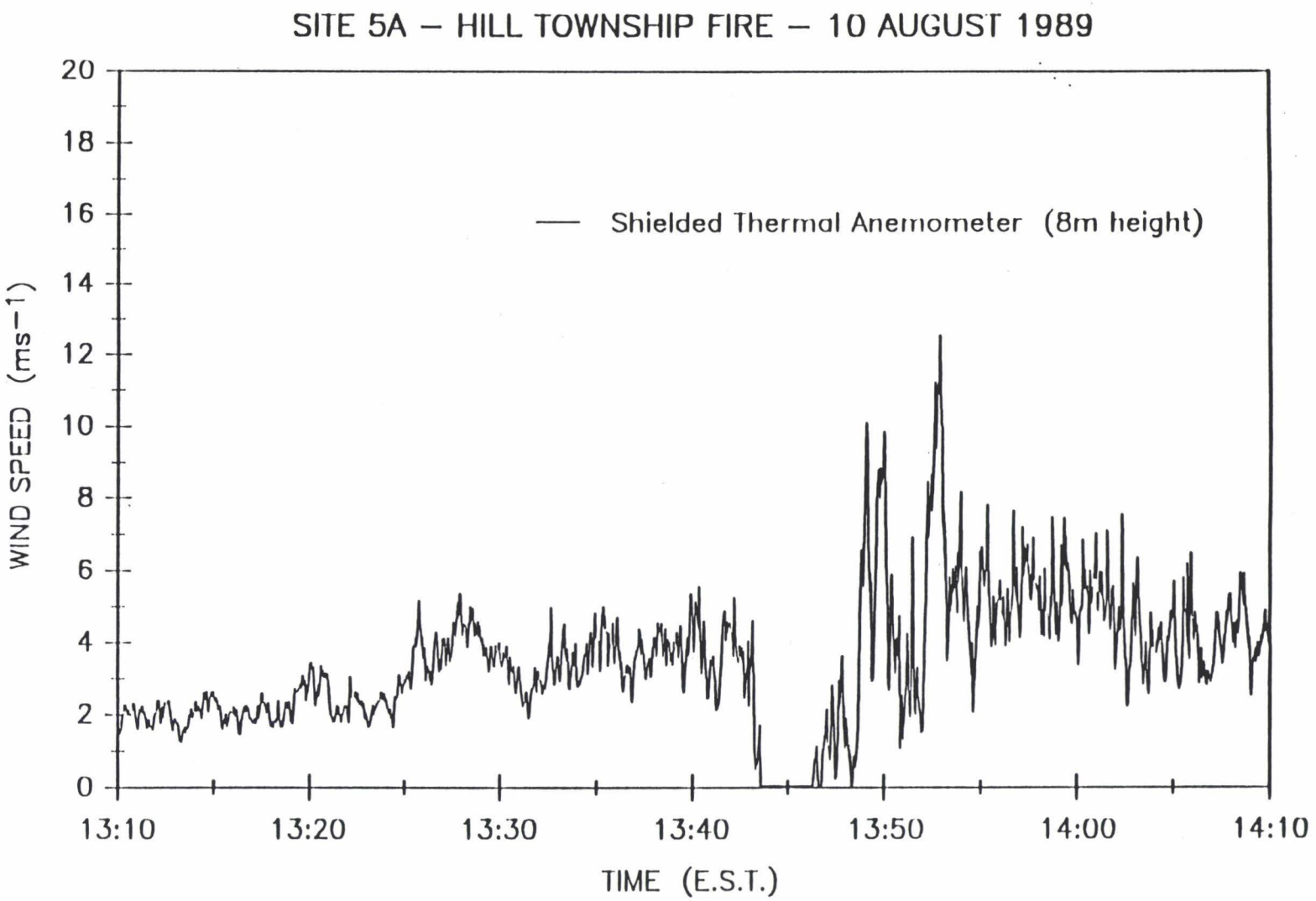
Shielded Thermocouples

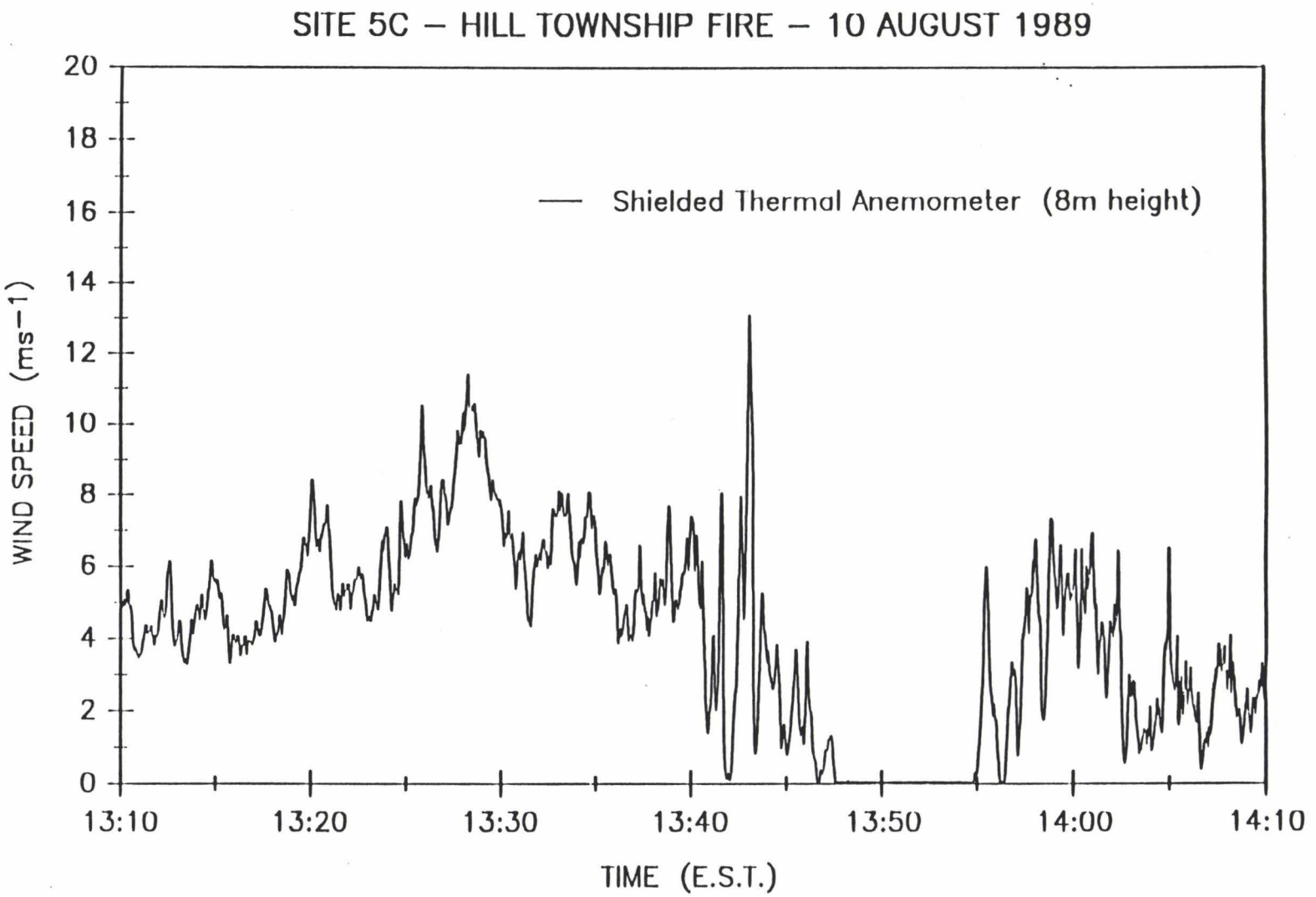
The thermocouples, small-bead welded and tested units proved quite reliable with only a few, quite obvious, failures due to mechanical stress. The exact effect of the shields however, has not been determined. The shields used, were, as specified by PSRC. Of the 45 shields deployed, 3 melted outright. The remainder survived but their thermal impact on the readings is still being determined. The thermocouple data should therefore be viewed with a little caution if detailed assessment is required. As general temperature data, however, it should prove useful. A more accurate indication of appropriate shield induced error bands should be possible when the analysis presently underway is completed. The thermocouple response time is on the order of 0.5 seconds. The shield effect on this number is not yet known.

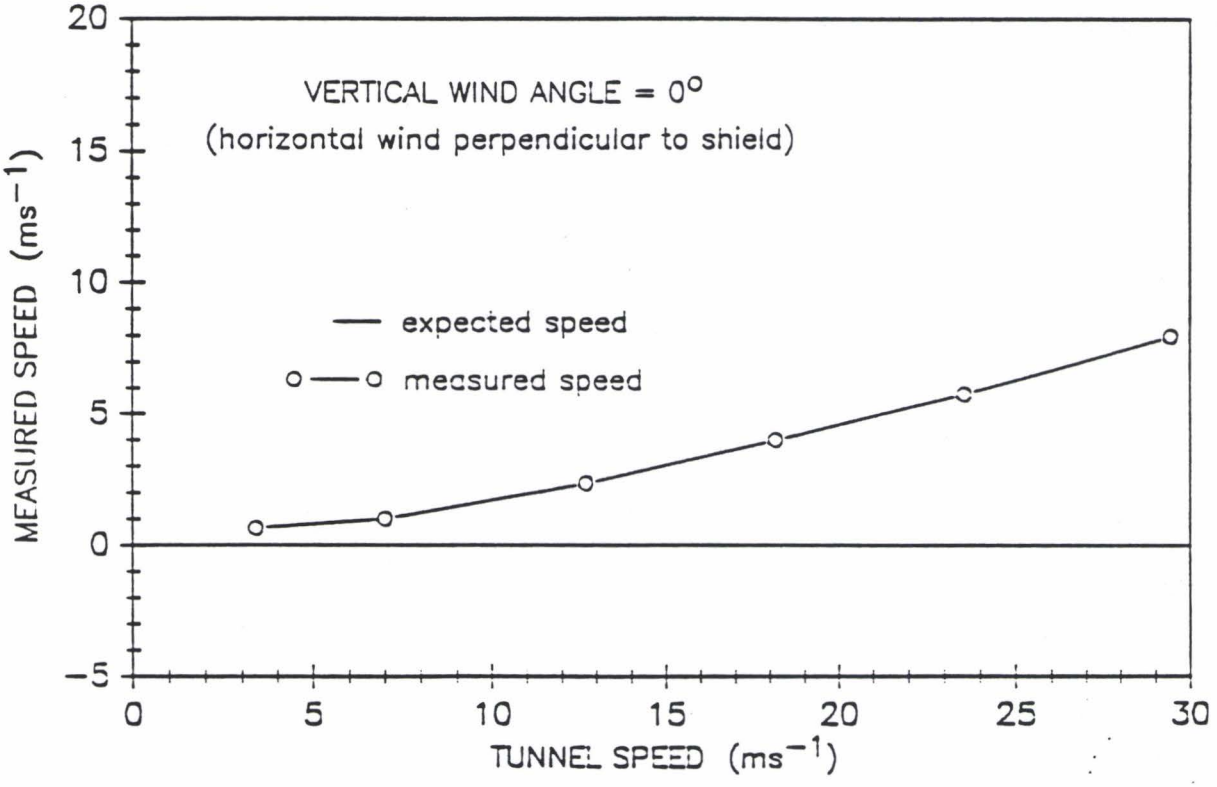
Data Integration Errors

Any data integration should keep in mind the limitations of 2 second scan rates, and less than 0.5 manual synchronization between the data loggers at these three sites and within each of the sites.


SITE 1C – HILL TOWNSHIP FIRE – 10 AUGUST 1989
Shielded Thermal Anemometer (8m height)
WIND SPEED (ms−1)
20
18
16
14
12
10
8
6
4
2
0
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)


SITE 5A – HILL TOWNSHIP FIRE – 10 AUGUST 1989
Shielded Thermal Anemometer (8m height)
WIND SPEED (ms−1)
0
2
4
6
8
10
12
14
16
18
20
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)


SITE 5C – HILL TOWNSHIP FIRE – 10 AUGUST 1989
Shielded Thermal Anemometer (8m height)
WIND SPEED (ms−1)
20
18
16
14
12
10
8
6
4
2
0
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)


VERTICAL WIND ANGLE = 0°
(horizontal wind perpendicular to shield)
expected speed
measured speed
MEASURED SPEED (ms⁻¹)
TUNNEL SPEED (ms⁻¹)
20
15
10
5
0
−5
0
5
10
15
20
25
30

DATA FORMAT ON FLOPPY DISKS

The Hill Township data collected by the University of Iowa have been placed on three floppy disks. Each diskette contains three LOTUS worksheet files, one file for each tower in a three tower array. Disk 1 also contains the file for a surface array of thermocouples.

All of the data sets cover a one hour period from 13:10 to 14:10 h (E.S.T.) on 10 August 1989. Note that the clock times are EASTERN STANDARD TIME - not daylight savings. Refer to the location map for site and tower identification.

The coding for the file names refer to: HT = Hill Township
HT1 = Site 1
HT1A = Tower A

The diskettes contain the following LOTUS worksheet files.

DISK 1	HT1A.WK1	=	Hill Township - Site 1 - Tower A
	HT1B.WK1	=	Hill Township - Site 1 - Tower B
	HT1C.WK1	=	Hill Township - Site 1 - Tower C
	HT1B-SA.WK1	=	Hill Township - Site 1 - Tower B - Surface Array
DISK 2	HT3A.WK1	=	Hill Township - Site 3 - Tower A
	HT3B.WK1	=	Hill Township - Site 3 - Tower B
	HT3C.WK1	=	Hill Township - Site 3 - Tower C
DISK 3	HT5A.WK1	=	Hill Township - Site 5 - Tower A
	HT5B.WK1	=	Hill Township - Site 5 - Tower B
	HT5C.WK1	=	Hill Township - Site 5 - Tower C

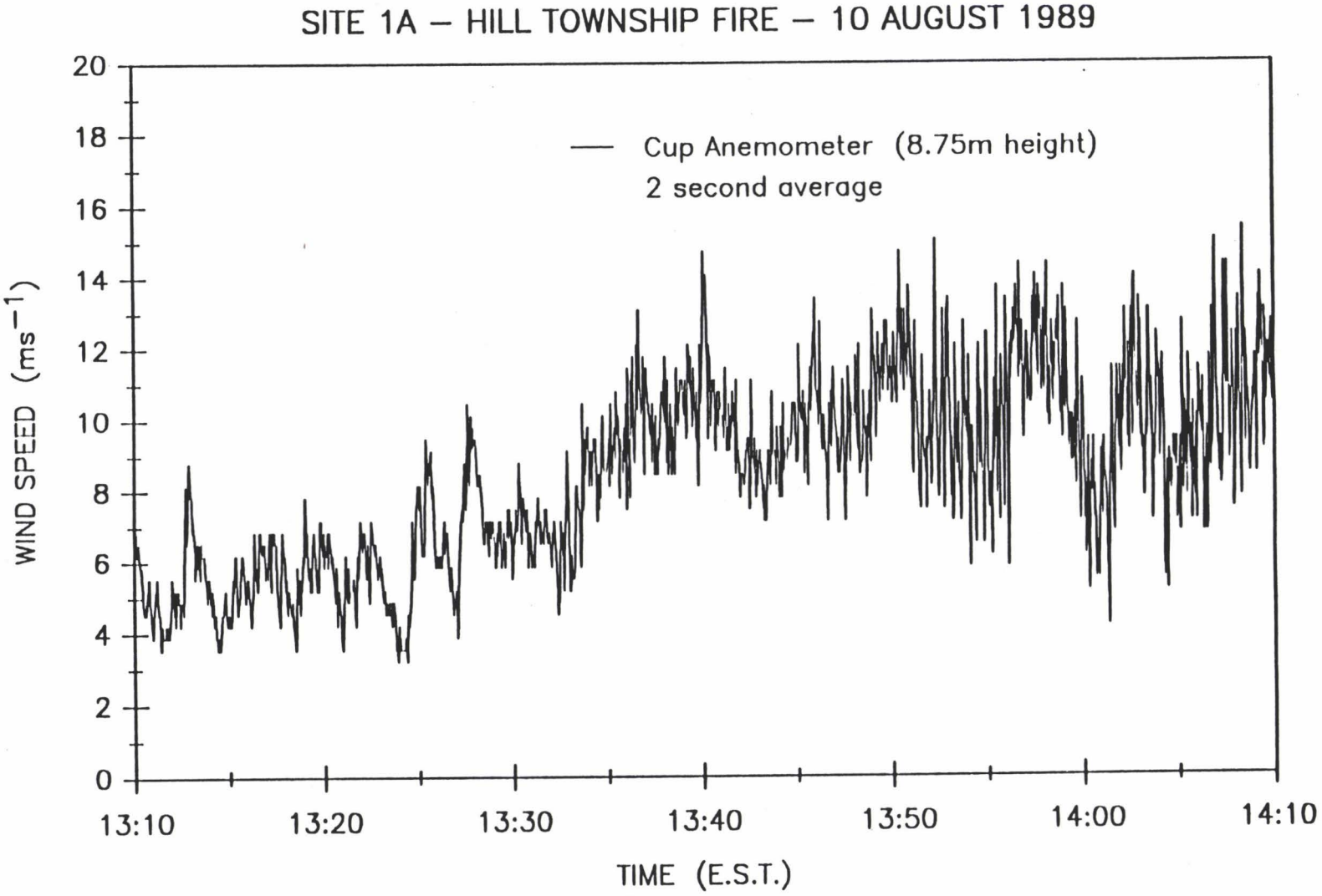
The column headings in each LOTUS worksheet file are organized in a similar manner.

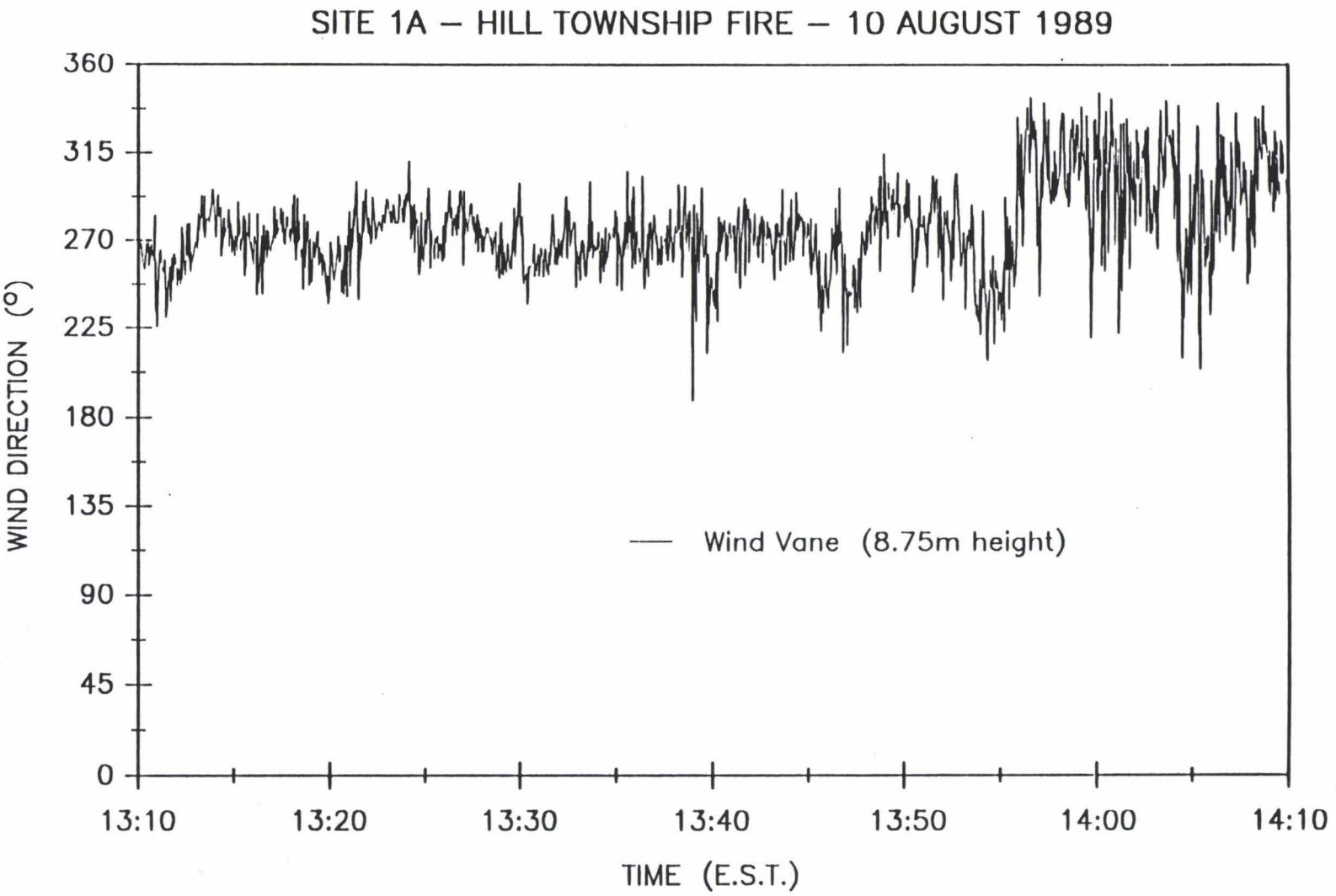
HR-MIN	=	Hour and Minute (E.S.T.)
SECOND	=	Seconds
8m	=	Thermocouple temperature measurement 8 m above the surface.
6m	=	Thermocouple temperature measurement 6 m above the surface.
3m	=	Thermocouple temperature measurement 3 m above the surface.
1.5m	=	Thermocouple temperature measurement 1.5 m above the surface.
0.75m	=	Thermocouple temperature measurement 0.75 m above the surface.
SURF*	=	Thermocouple temperature measurement on the surface.
SPEED	=	The average wind speed over a 2 s period expressed in ms^{-1}.
DIRECT	=	Instantaneous wind direction from True North.

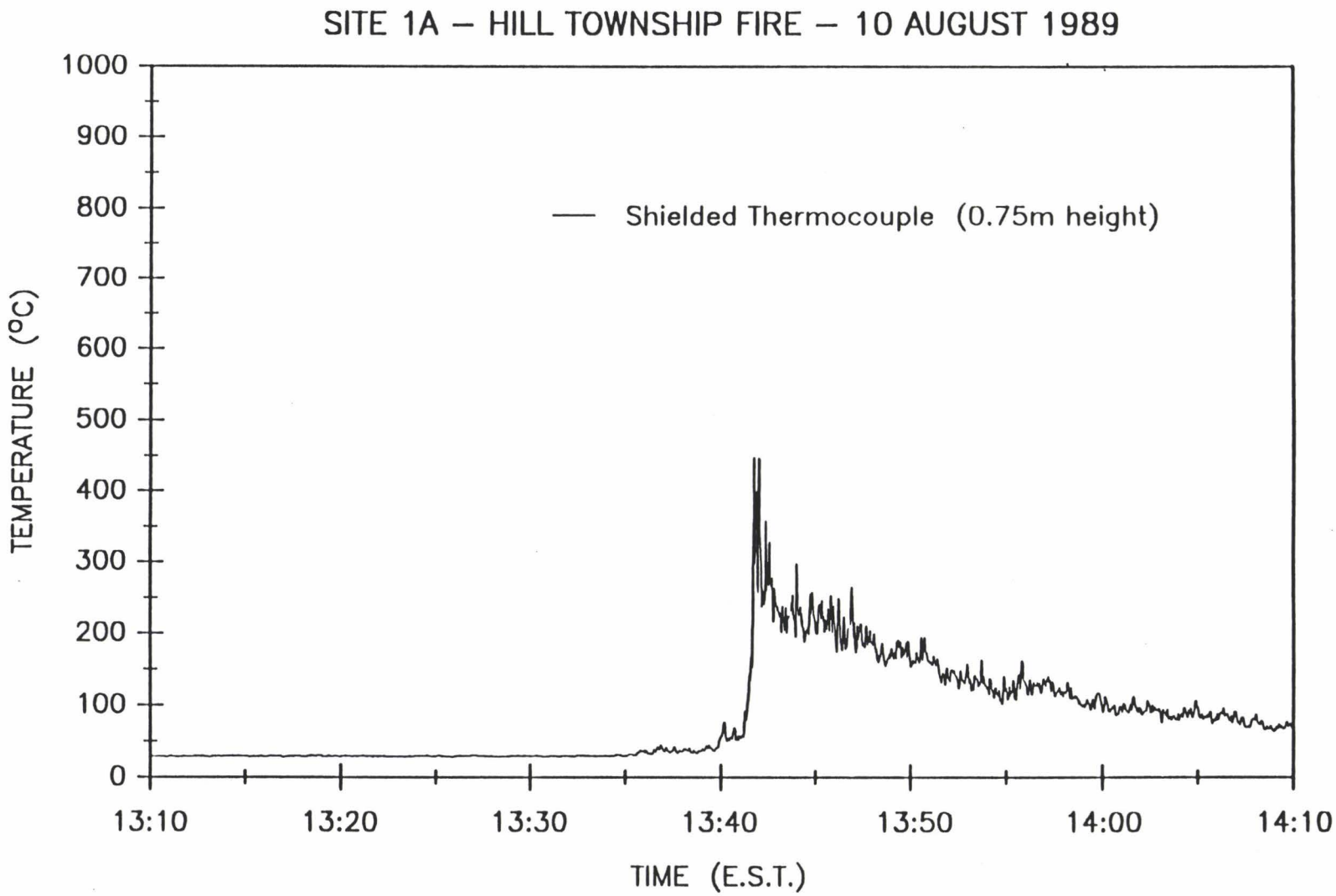
* *Note: surface temperatures were not collected at all towers.*

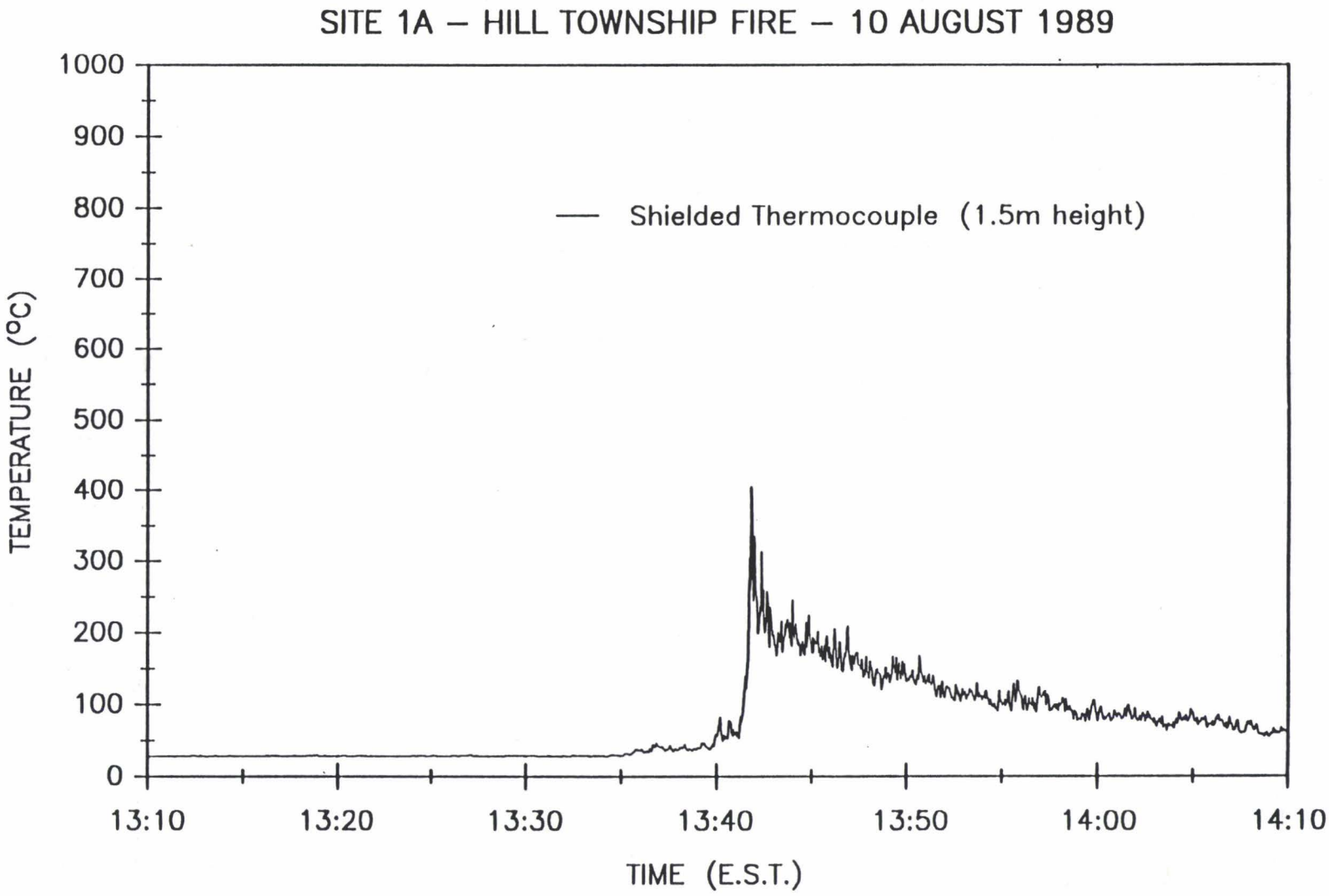
COMPILATION OF DATA

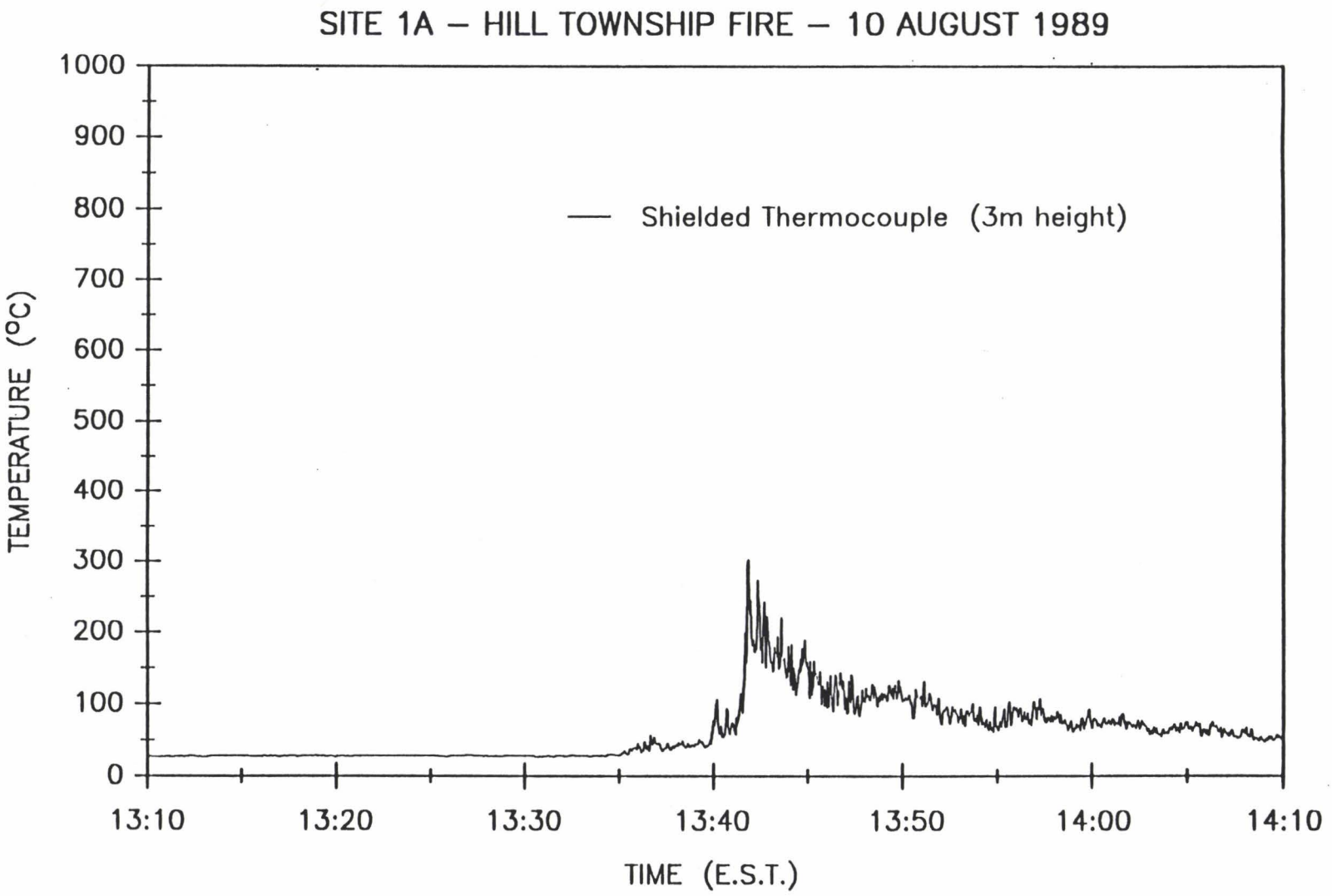
SITE 1 - TOWER A

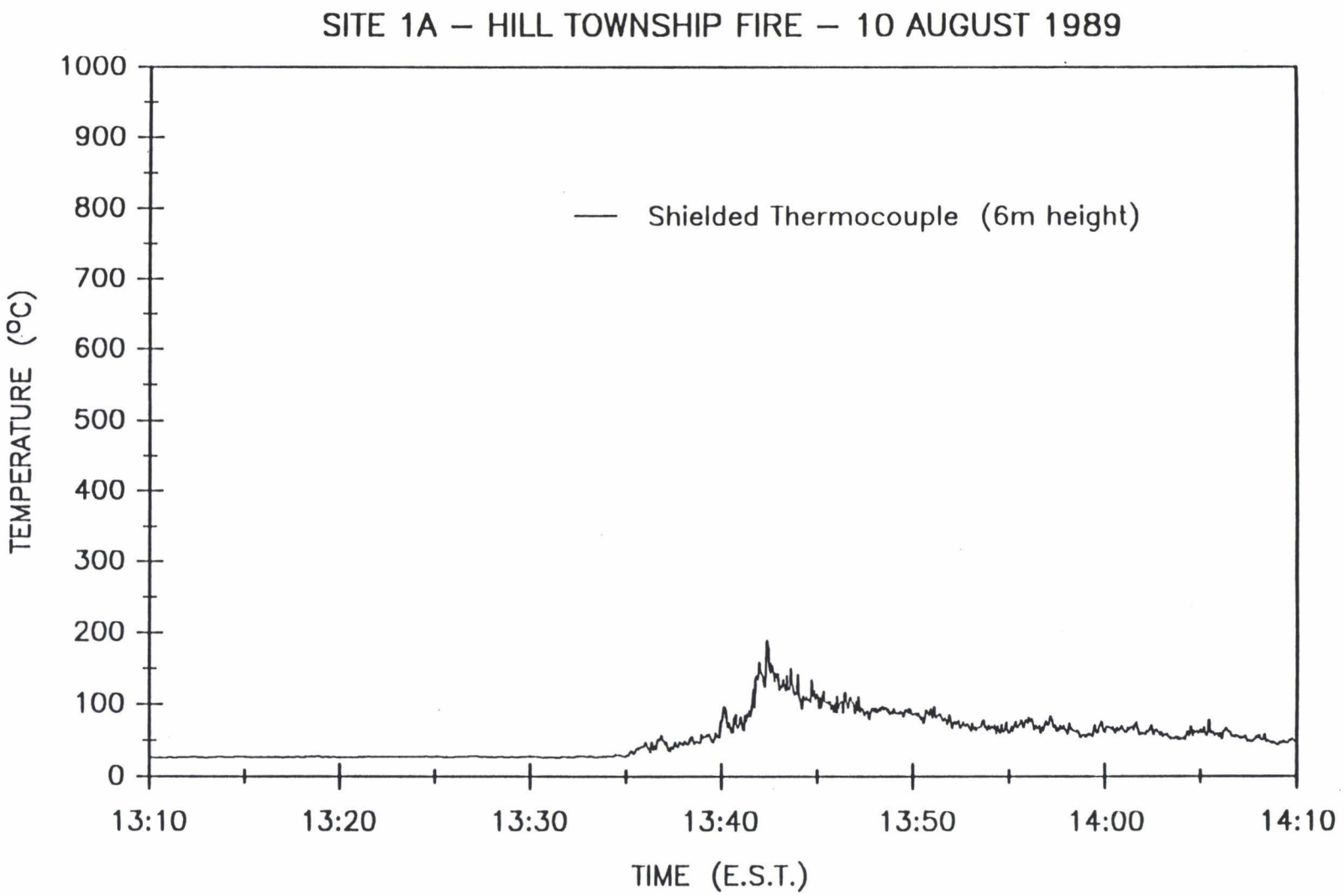

SITE 1A – HILL TOWNSHIP FIRE – 10 AUGUST 1989
Cup Anemometer (8.75m height)
2 second average
WIND SPEED (ms^{-1})
20
18
16
14
12
10
8
6
4
2
0
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)

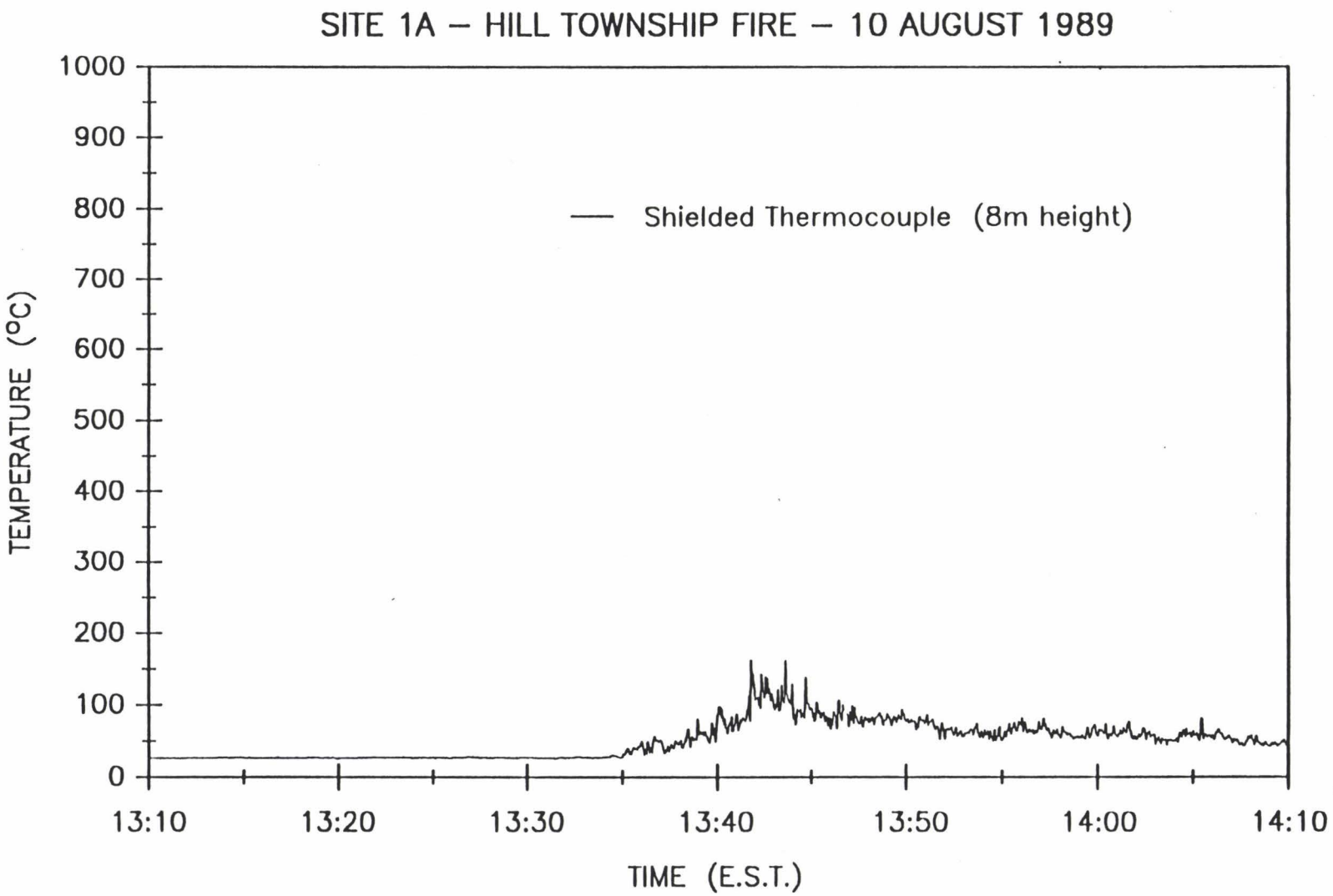

SITE 1A – HILL TOWNSHIP FIRE – 10 AUGUST 1989
WIND DIRECTION (°)
360
315
270
225
180
135
90
45
0
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)
Wind Vane (8.75m height)


SITE 1A – HILL TOWNSHIP FIRE – 10 AUGUST 1989
TEMPERATURE (°C)
1000
900
800
700
600
500
400
300
200
100
0
Shielded Thermocouple (0.75m height)
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)

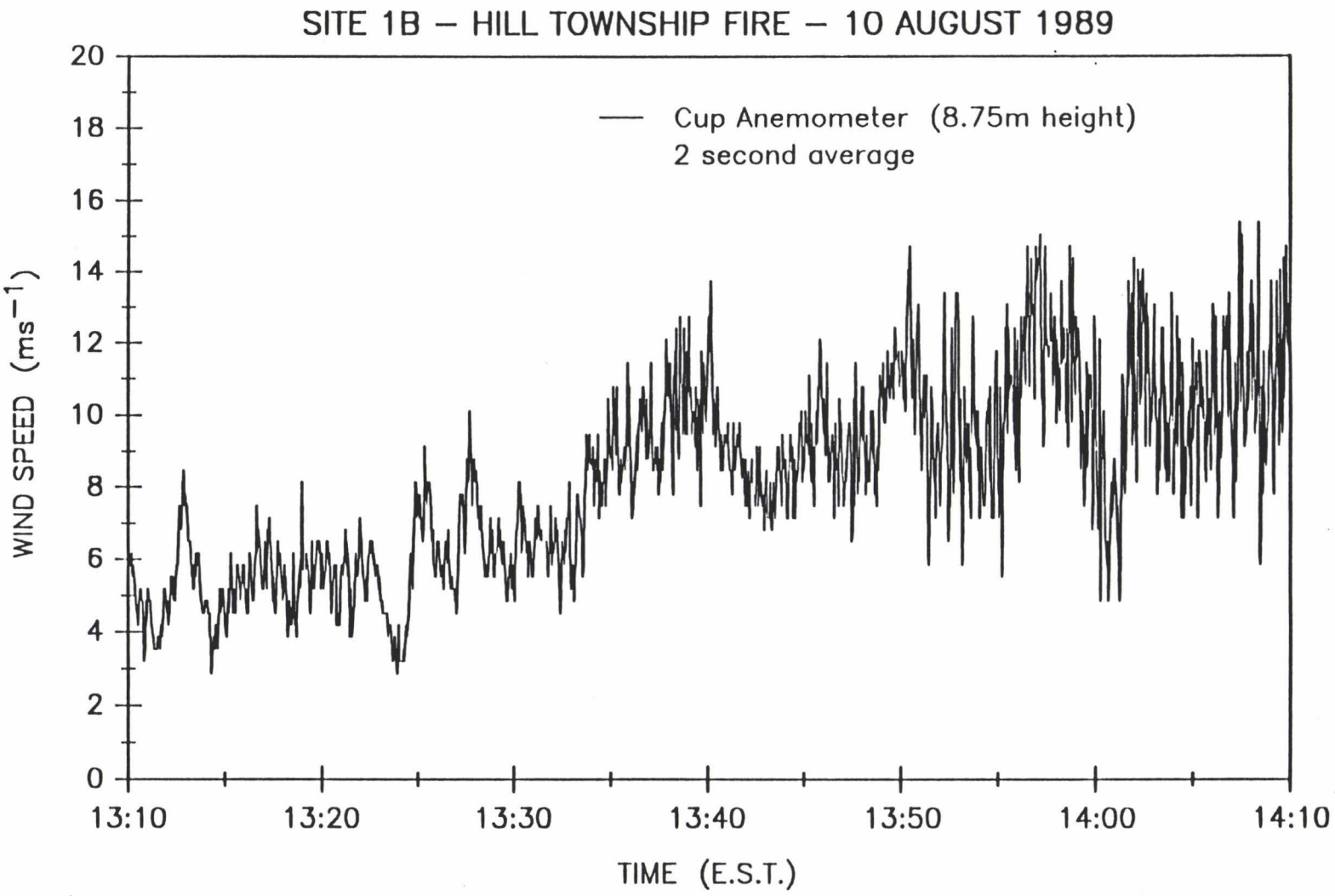

SITE 1A – HILL TOWNSHIP FIRE – 10 AUGUST 1989
Shielded Thermocouple (1.5m height)
TEMPERATURE (°C)
1000
900
800
700
600
500
400
300
200
100
0
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)

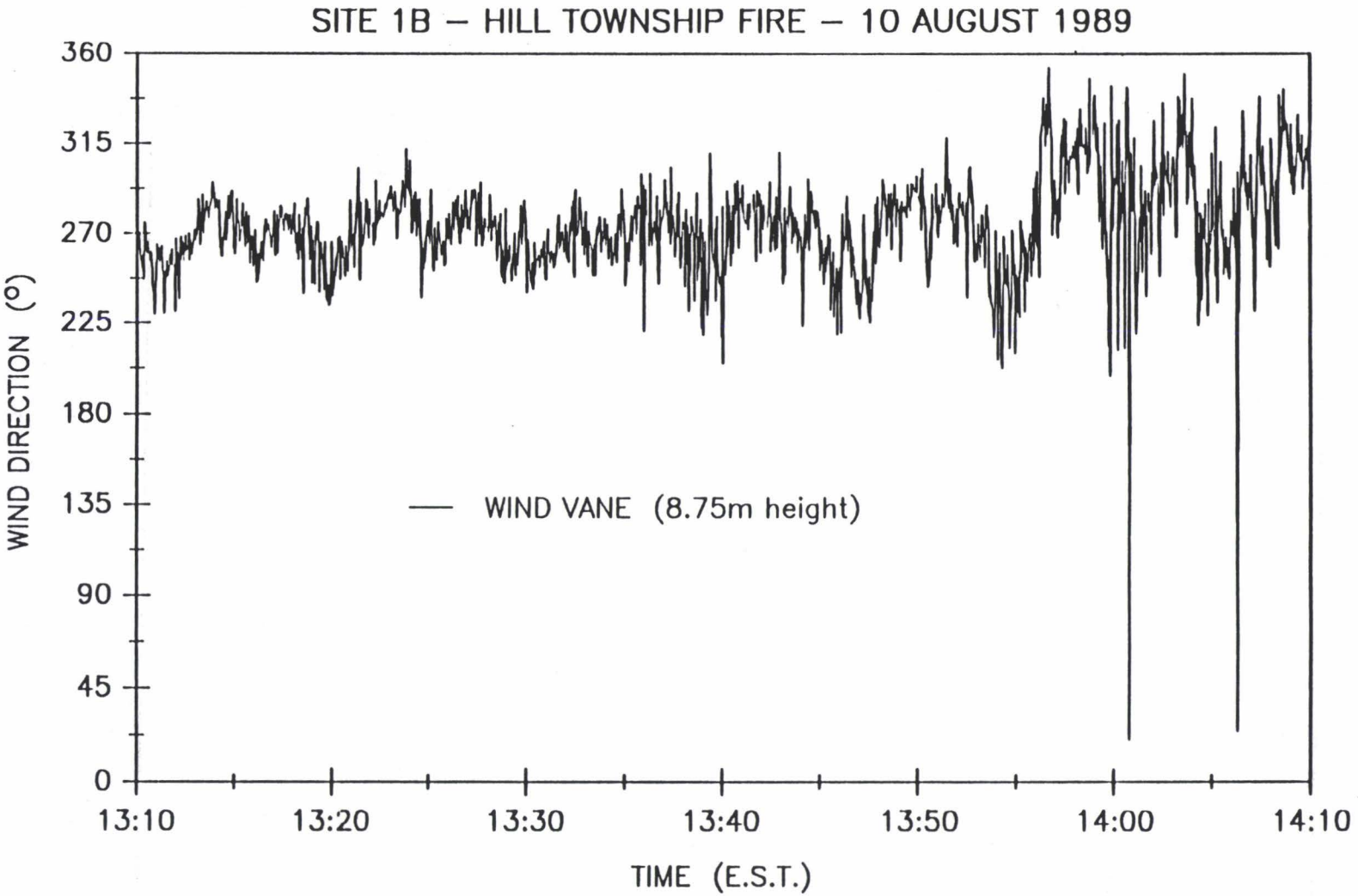

SITE 1A – HILL TOWNSHIP FIRE – 10 AUGUST 1989
Shielded Thermocouple (3m height)
TEMPERATURE (°C)
1000
900
800
700
600
500
400
300
200
100
0
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)

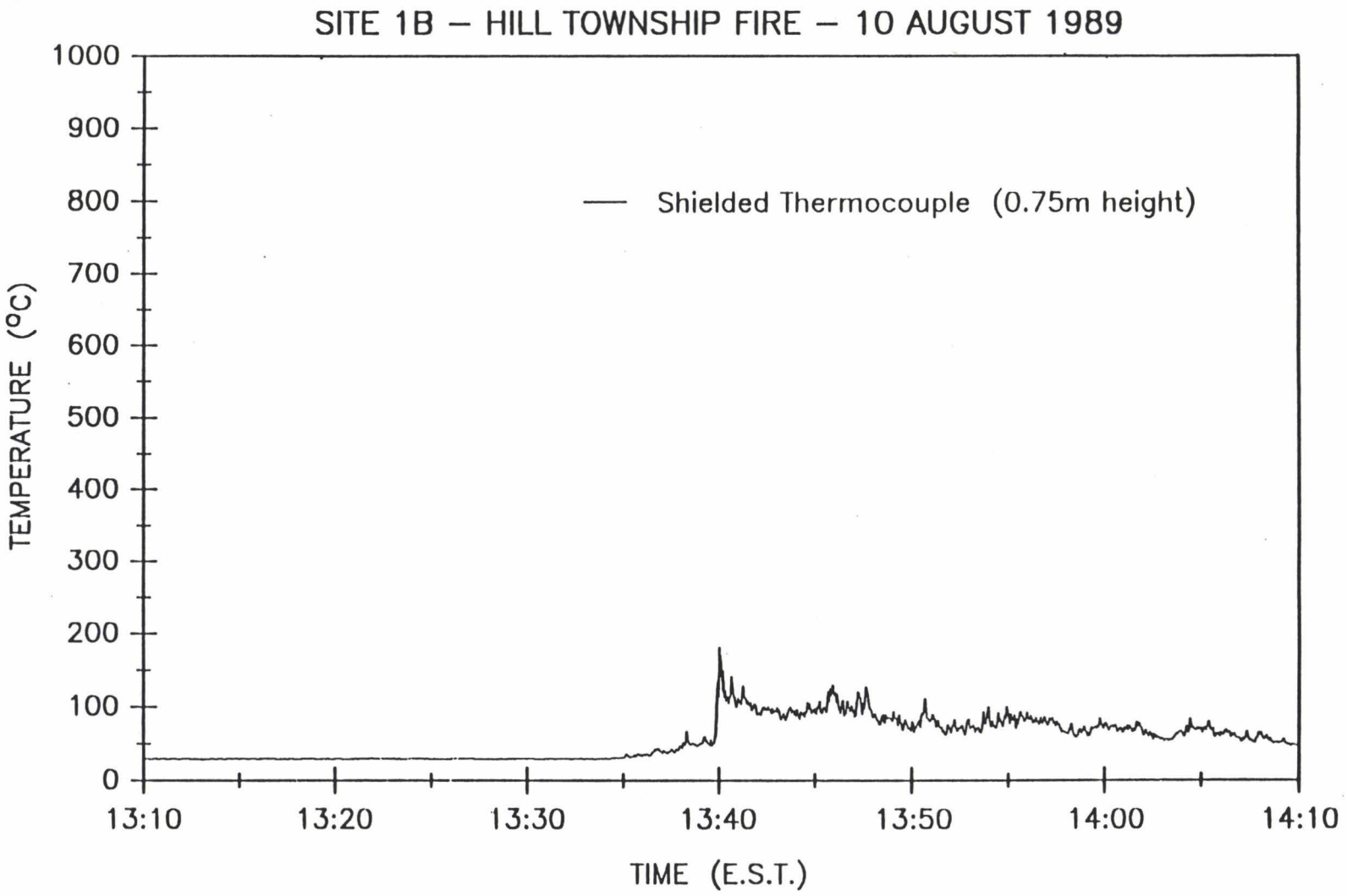

SITE 1A – HILL TOWNSHIP FIRE – 10 AUGUST 1989
Shielded Thermocouple (6m height)
TEMPERATURE (°C)
1000
900
800
700
600
500
400
300
200
100
0
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)

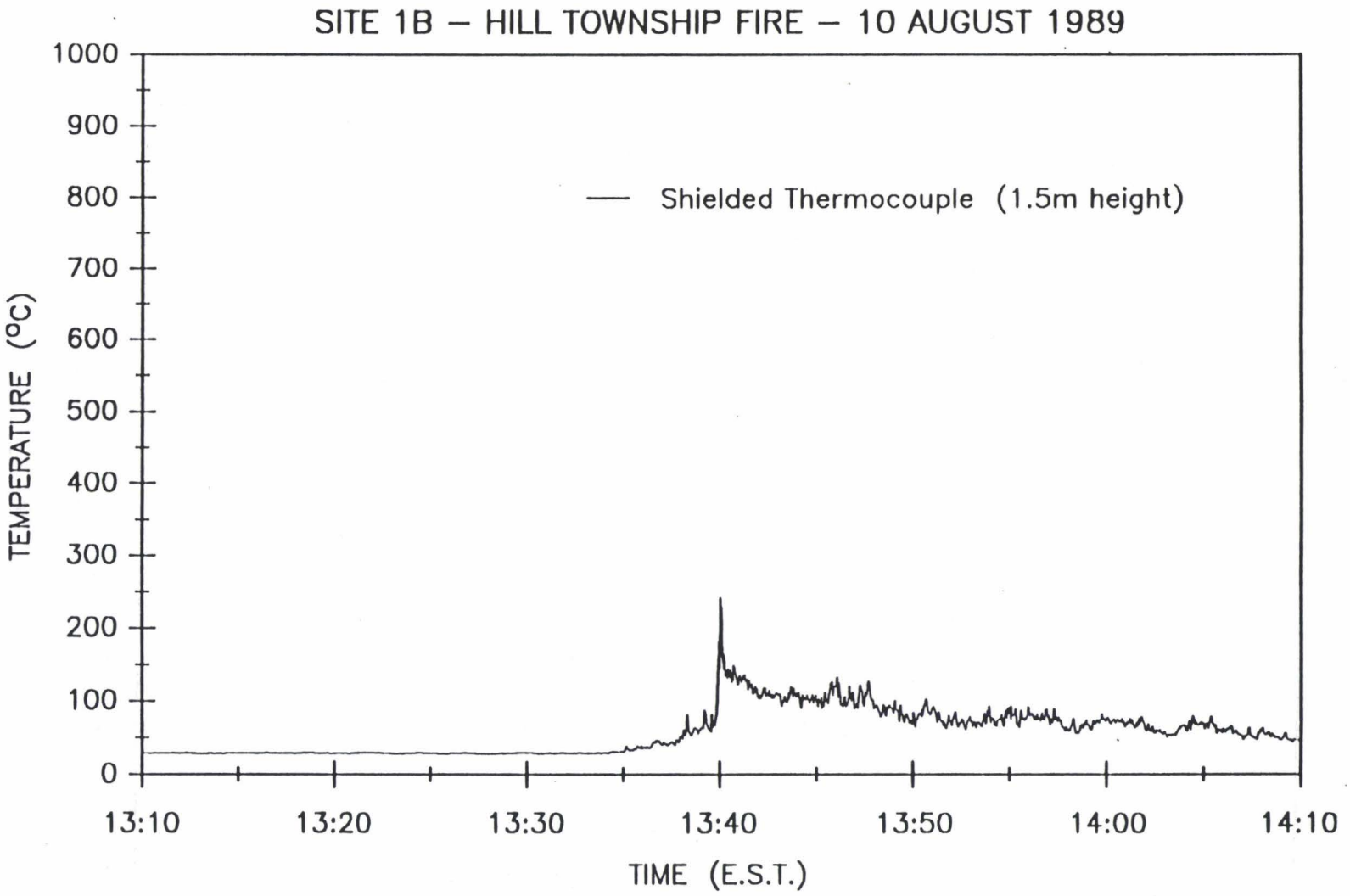

SITE 1A – HILL TOWNSHIP FIRE – 10 AUGUST 1989
1000
900
800
700
600
500
400
300
200
100
0
TEMPERATURE (°C)
Shielded Thermocouple (8m height)
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)

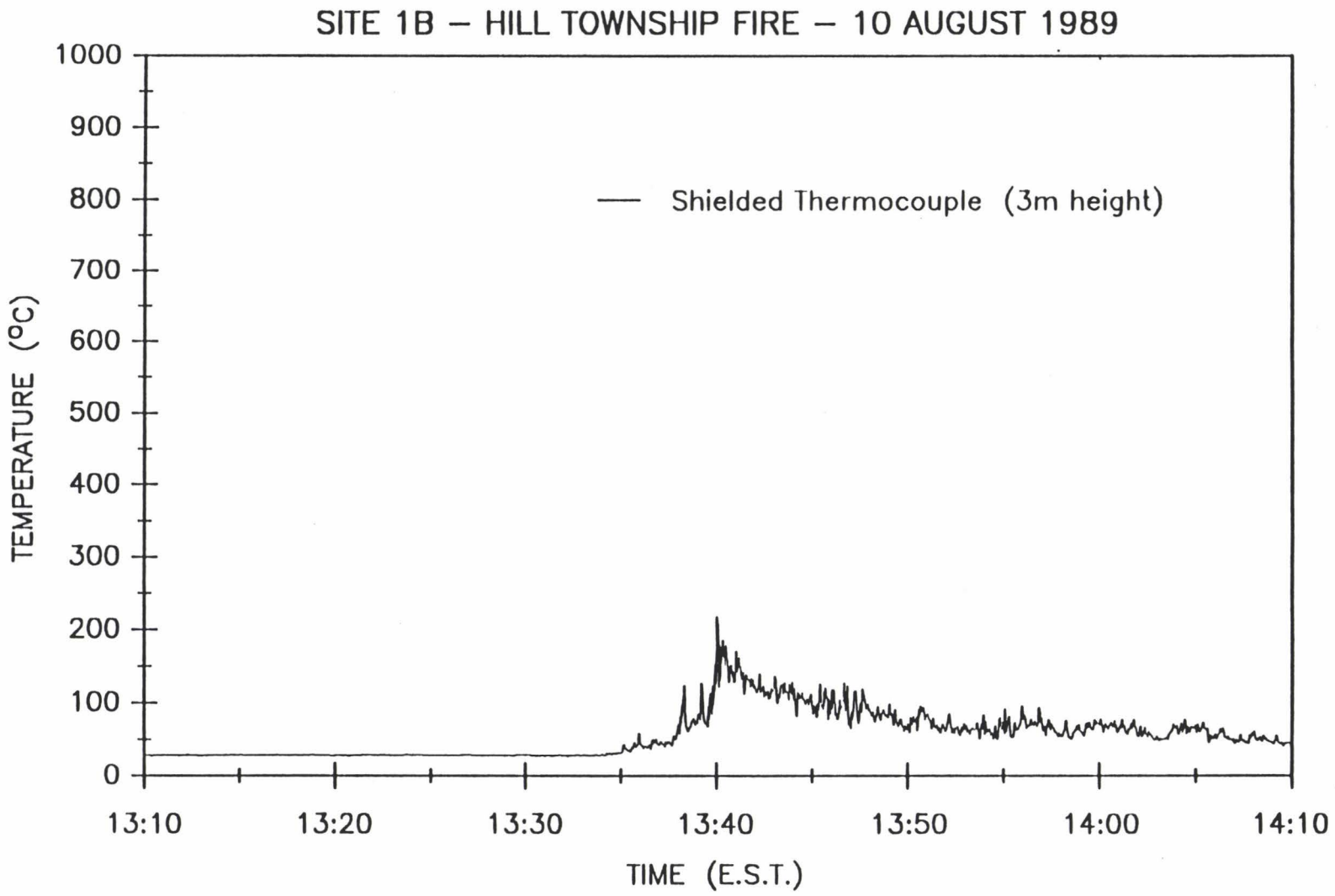
SITE 1 - TOWER B

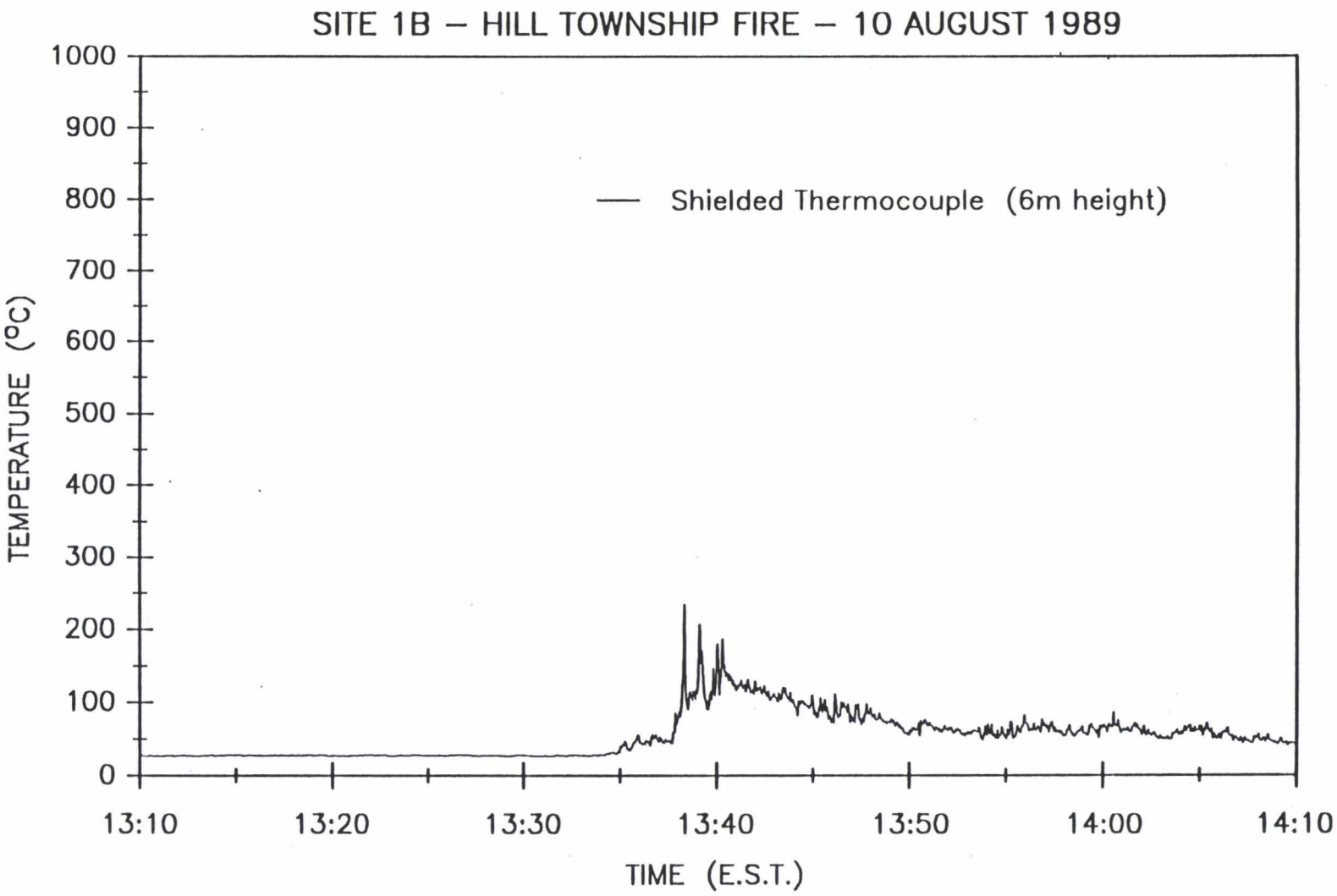

SITE 1B – HILL TOWNSHIP FIRE – 10 AUGUST 1989
Cup Anemometer (8.75m height)
2 second average
WIND SPEED (ms⁻¹)
0
2
4
6
8
10
12
14
16
18
20
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)

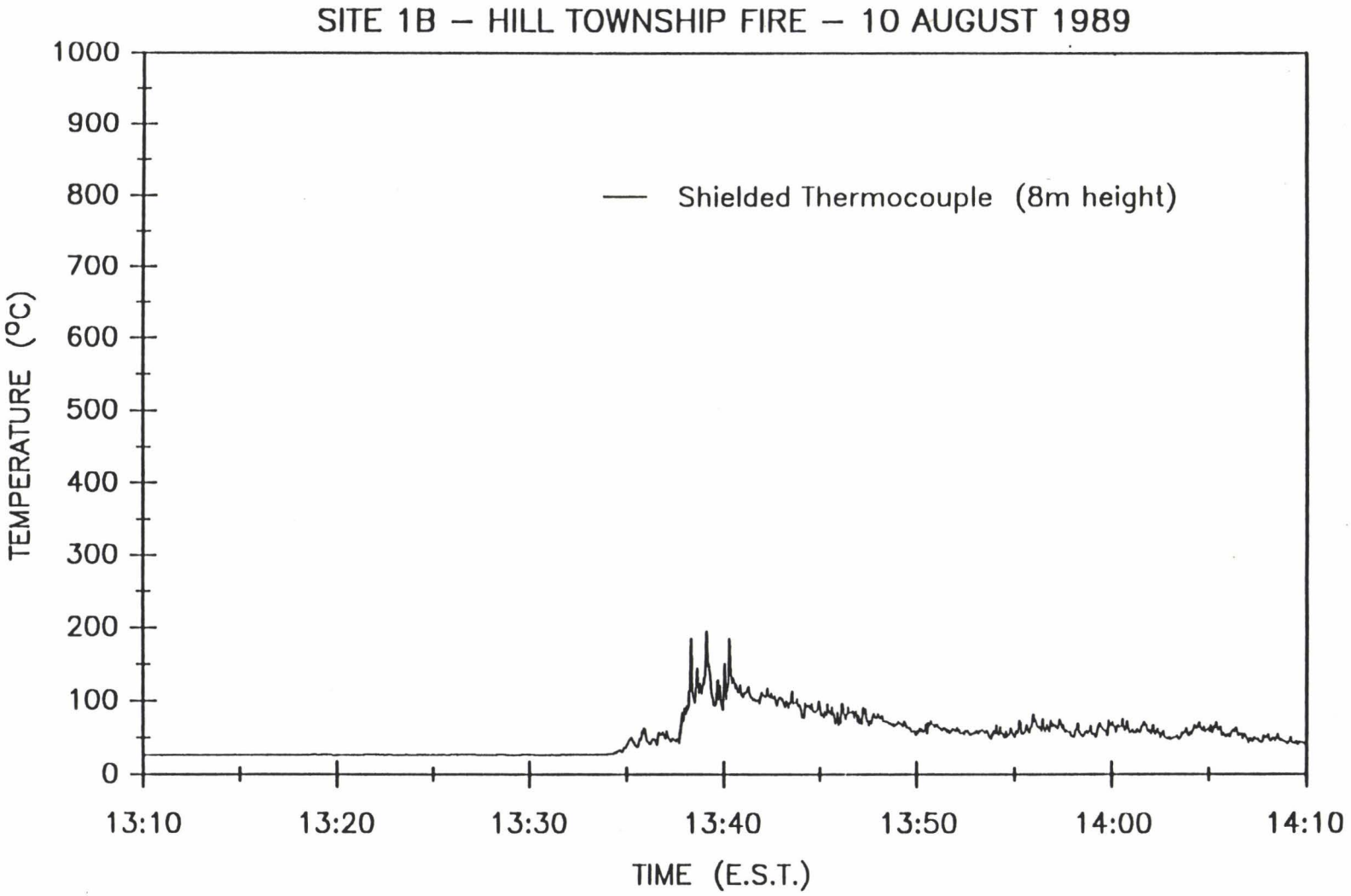

SITE 1B – HILL TOWNSHIP FIRE – 10 AUGUST 1989
WIND DIRECTION (°)
360
315
270
225
180
135
90
45
0
WIND VANE (8.75m height)
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)


SITE 1B – HILL TOWNSHIP FIRE – 10 AUGUST 1989
1000
900
800
700
600
500
400
300
200
100
0
TEMPERATURE (°C)
Shielded Thermocouple (0.75m height)
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)


SITE 1B – HILL TOWNSHIP FIRE – 10 AUGUST 1989
Shielded Thermocouple (1.5m height)
TEMPERATURE (°C)
1000
900
800
700
600
500
400
300
200
100
0
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)

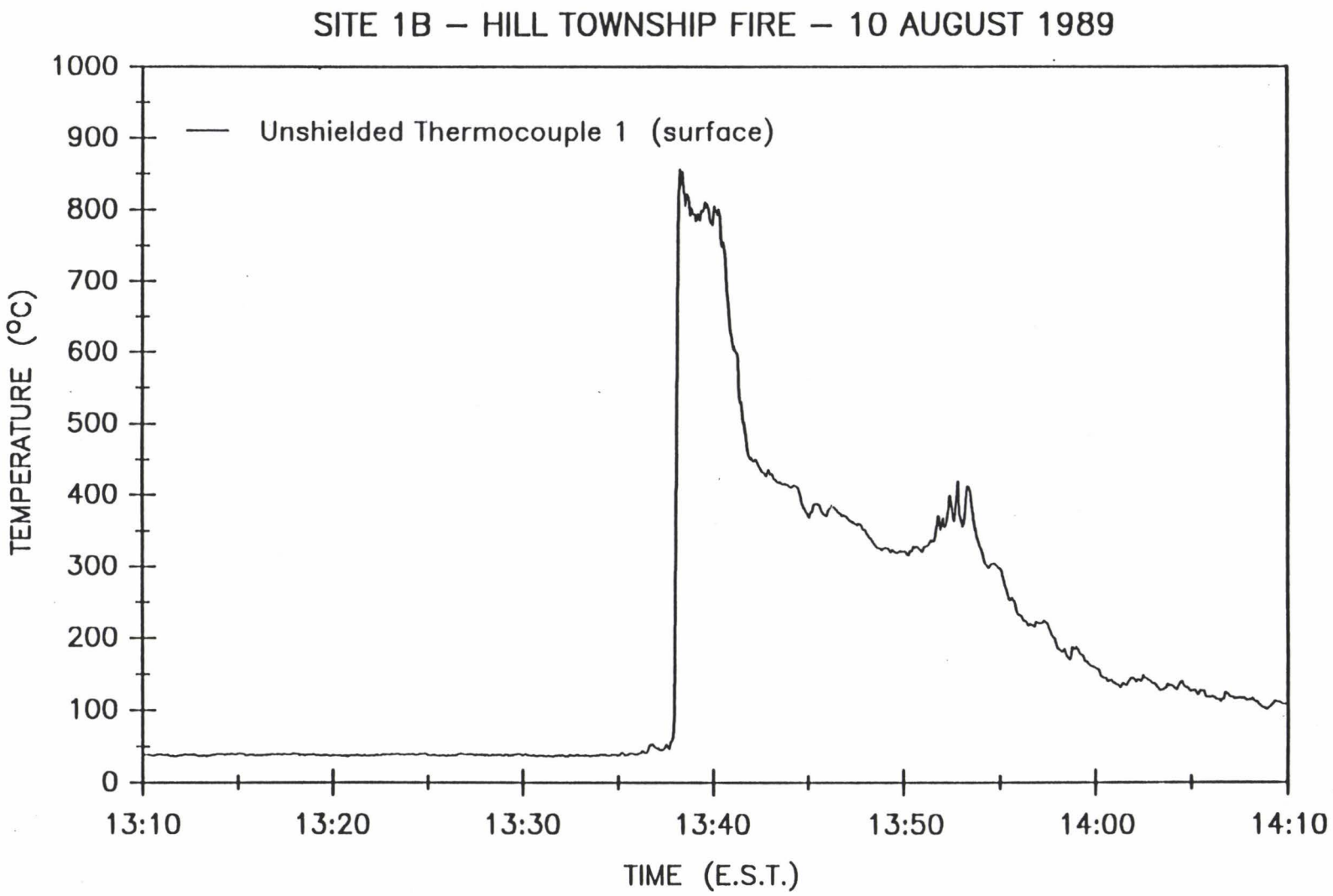

SITE 1B – HILL TOWNSHIP FIRE – 10 AUGUST 1989
Shielded Thermocouple (3m height)
TEMPERATURE (°C)
1000
900
800
700
600
500
400
300
200
100
0
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)

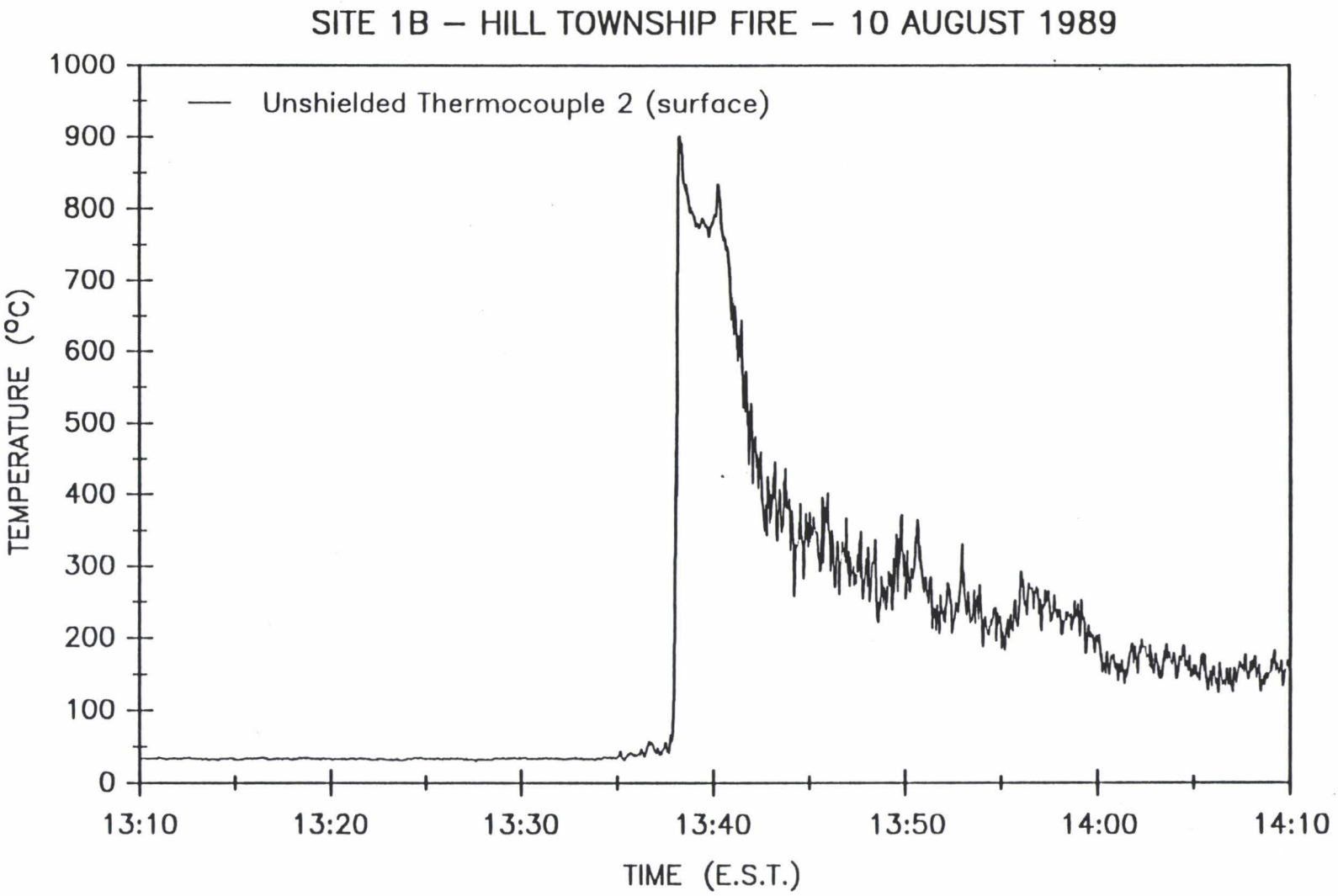

SITE 1B – HILL TOWNSHIP FIRE – 10 AUGUST 1989
1000
900
800
700
600
500
400
300
200
100
0
TEMPERATURE (°C)
Shielded Thermocouple (6m height)
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)

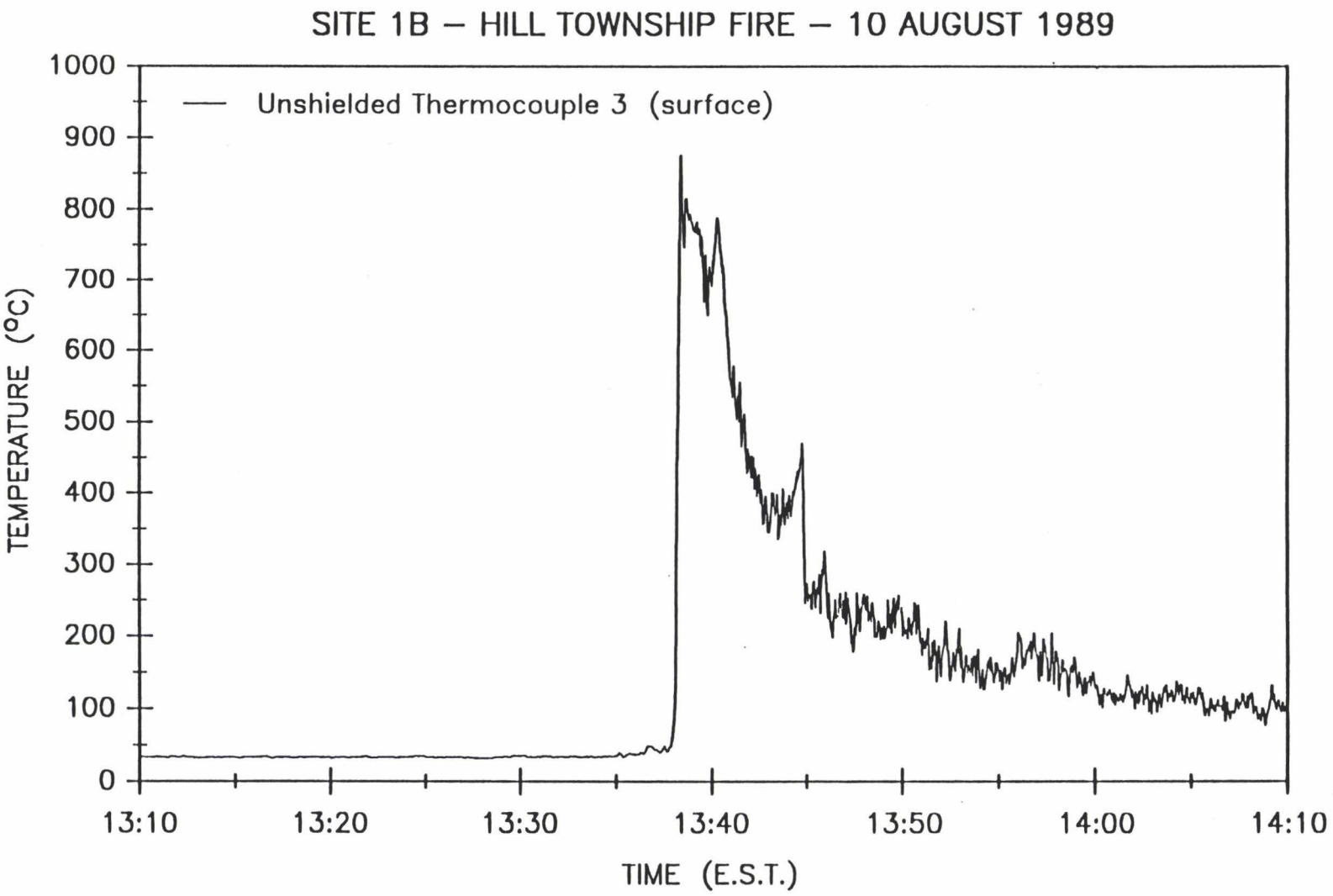

SITE 1B – HILL TOWNSHIP FIRE – 10 AUGUST 1989
1000
900
800
700
600
500
400
300
200
100
0
TEMPERATURE (°C)
Shielded Thermocouple (8m height)
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)

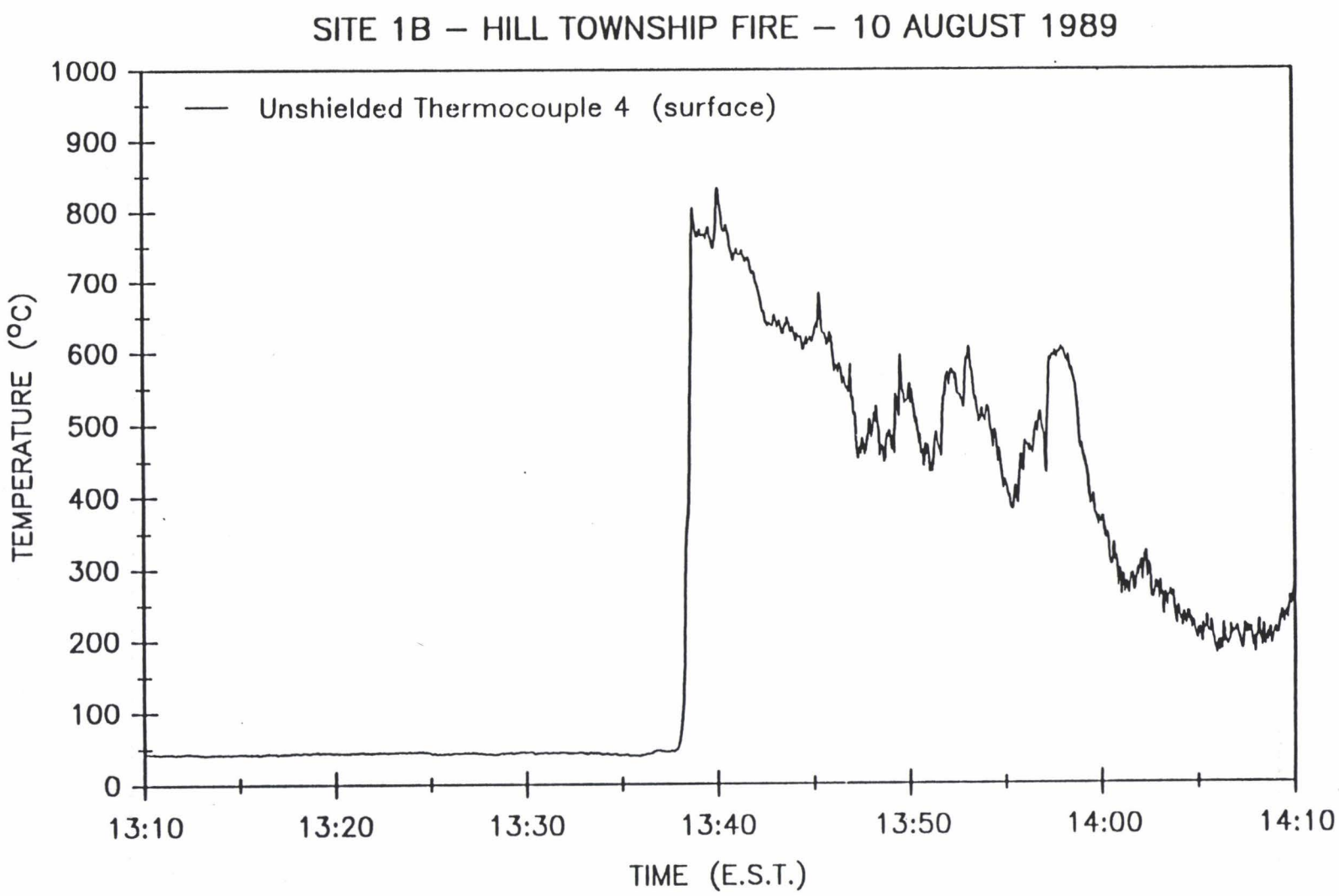
SITE 1 - TOWER B

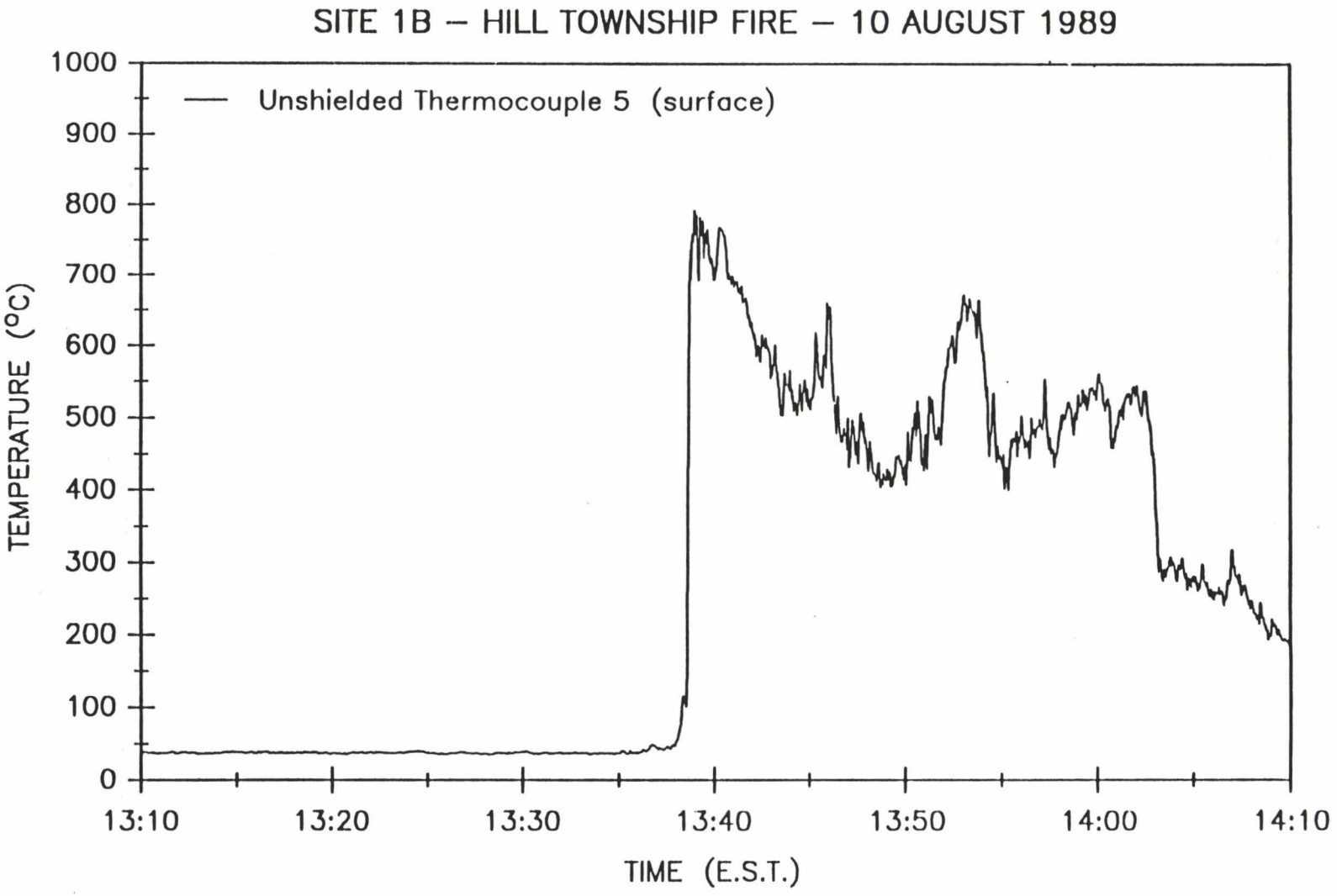
SPREAD ARRAY OF THERMOCOUPLES

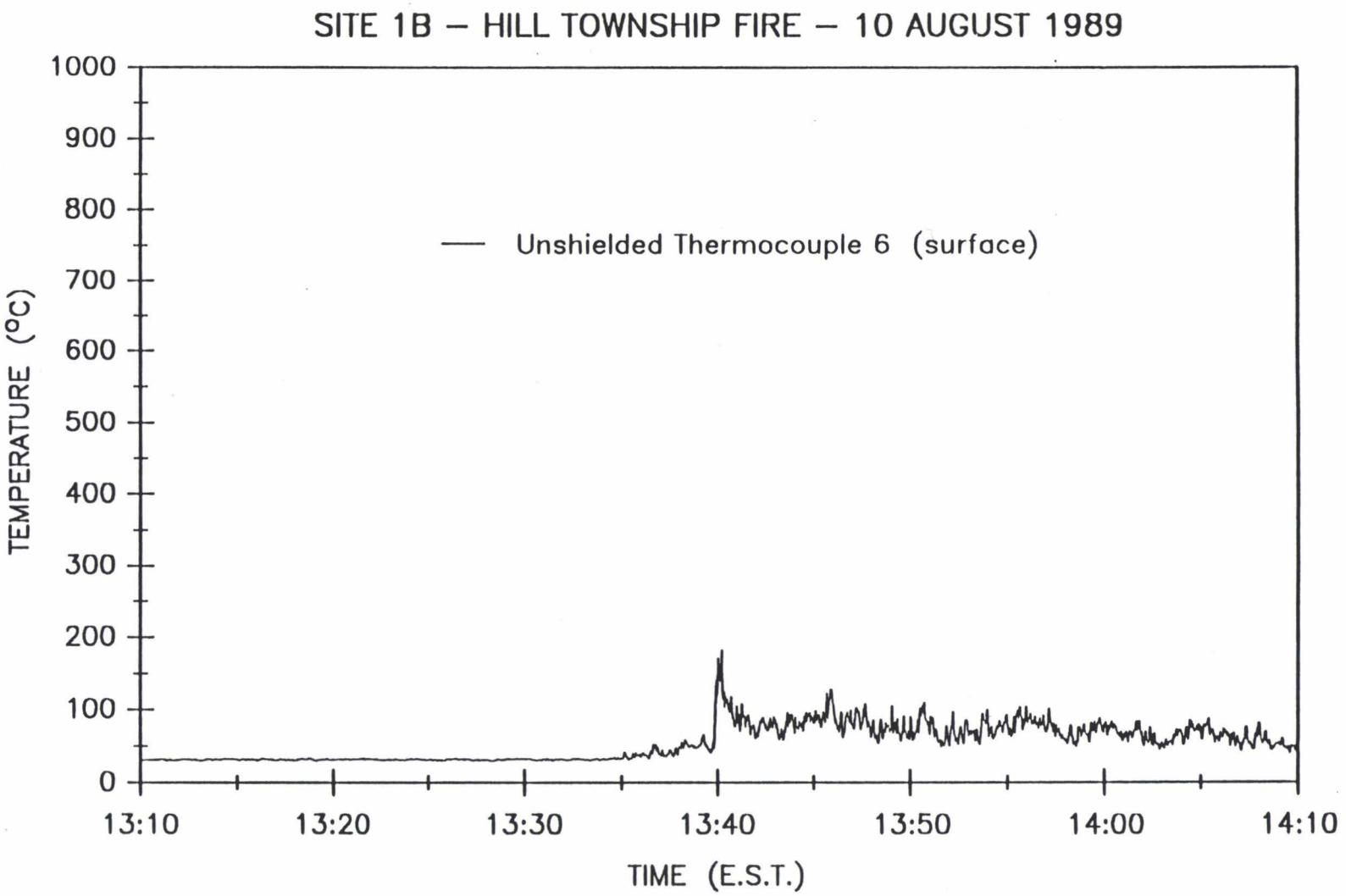

SITE 1B – HILL TOWNSHIP FIRE – 10 AUGUST 1989
Unshielded Thermocouple 1 (surface)
TEMPERATURE (°C)
1000
900
800
700
600
500
400
300
200
100
0
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)

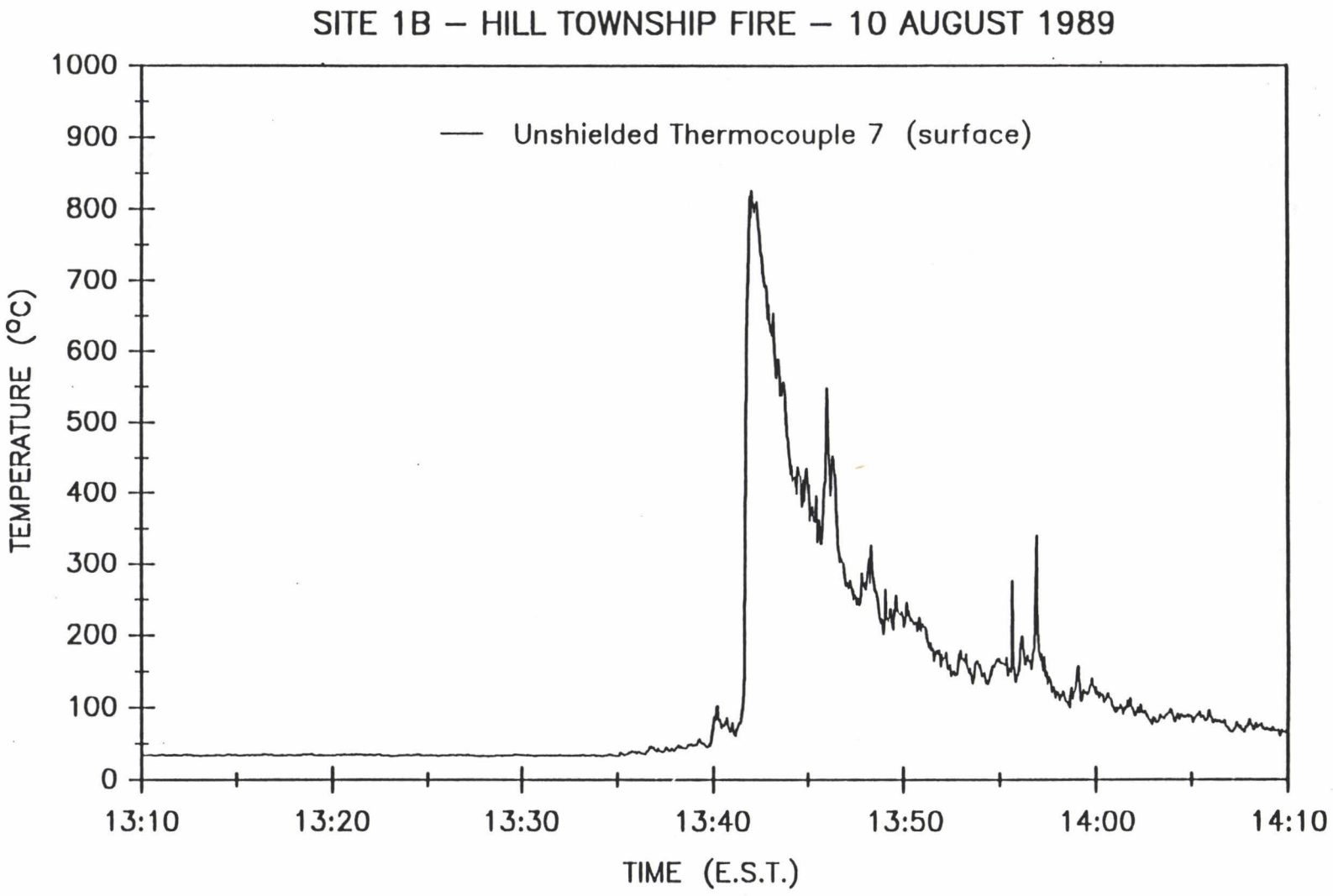

SITE 1B – HILL TOWNSHIP FIRE – 10 AUGUST 1989
Unshielded Thermocouple 2 (surface)
TEMPERATURE (°C)
1000
900
800
700
600
500
400
300
200
100
0
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)

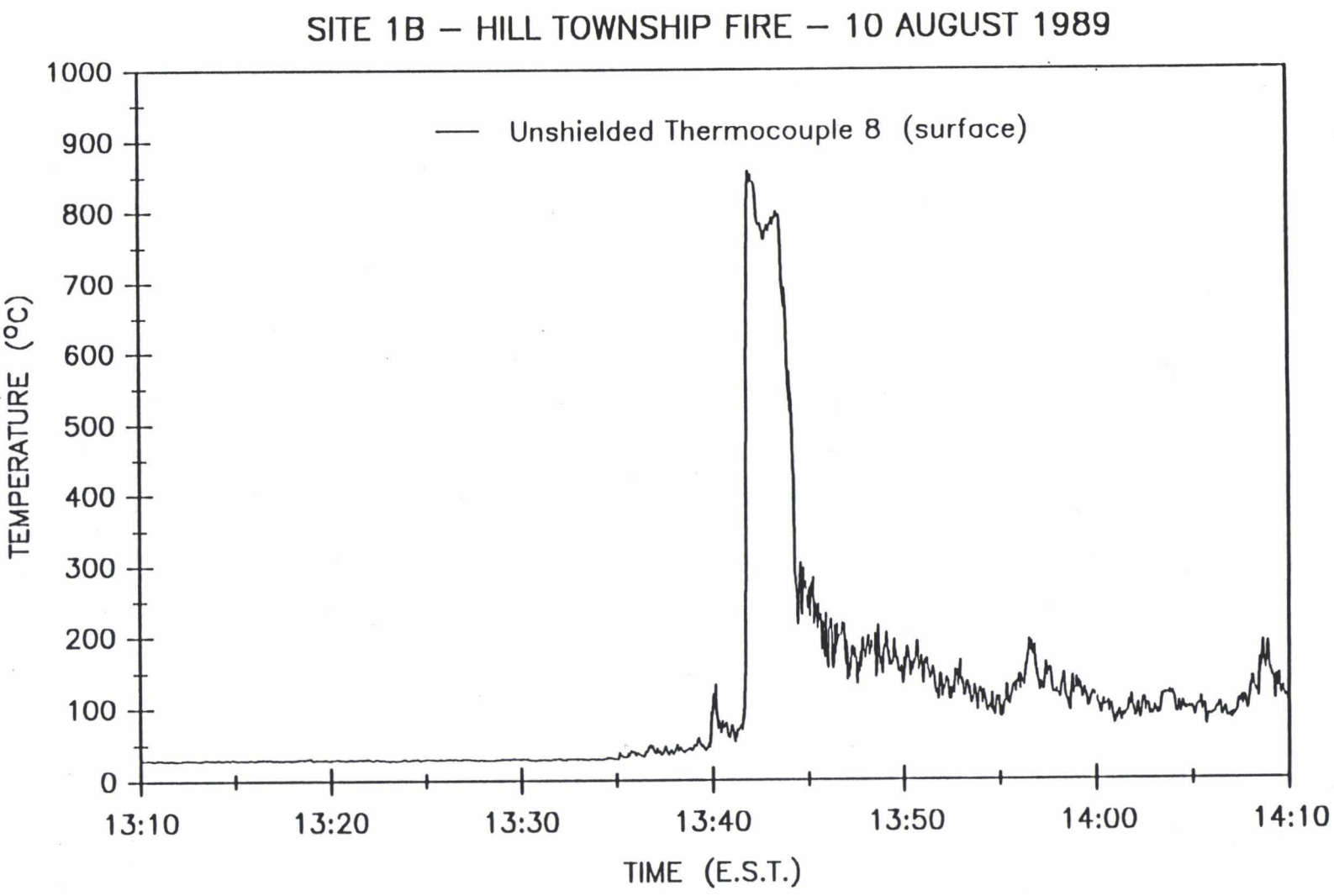

SITE 1B – HILL TOWNSHIP FIRE – 10 AUGUST 1989
Unshielded Thermocouple 3 (surface)
TEMPERATURE (°C)
1000
900
800
700
600
500
400
300
200
100
0
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)

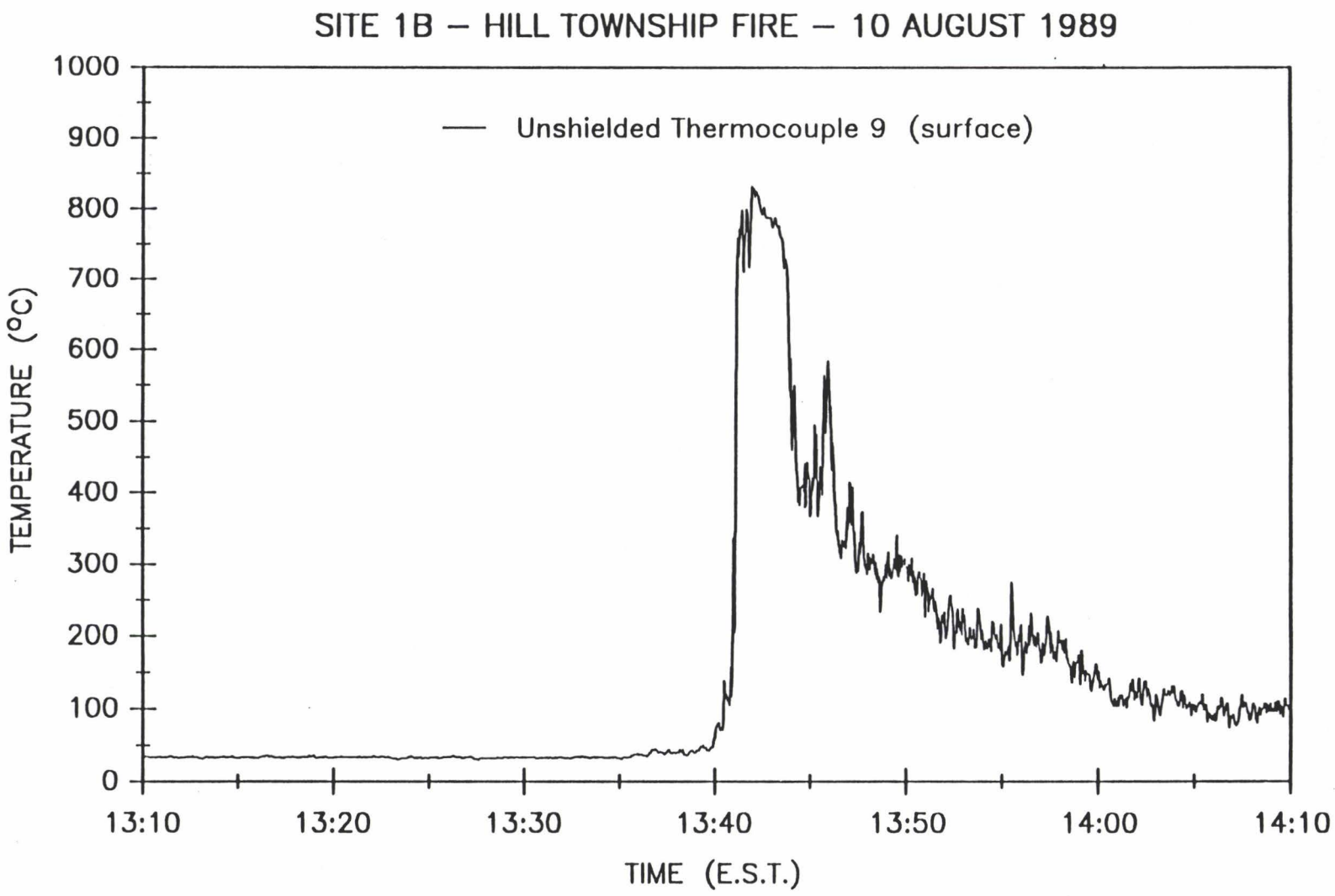

SITE 1B – HILL TOWNSHIP FIRE – 10 AUGUST 1989
Unshielded Thermocouple 4 (surface)
TEMPERATURE (°C)
1000
900
800
700
600
500
400
300
200
100
0
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)

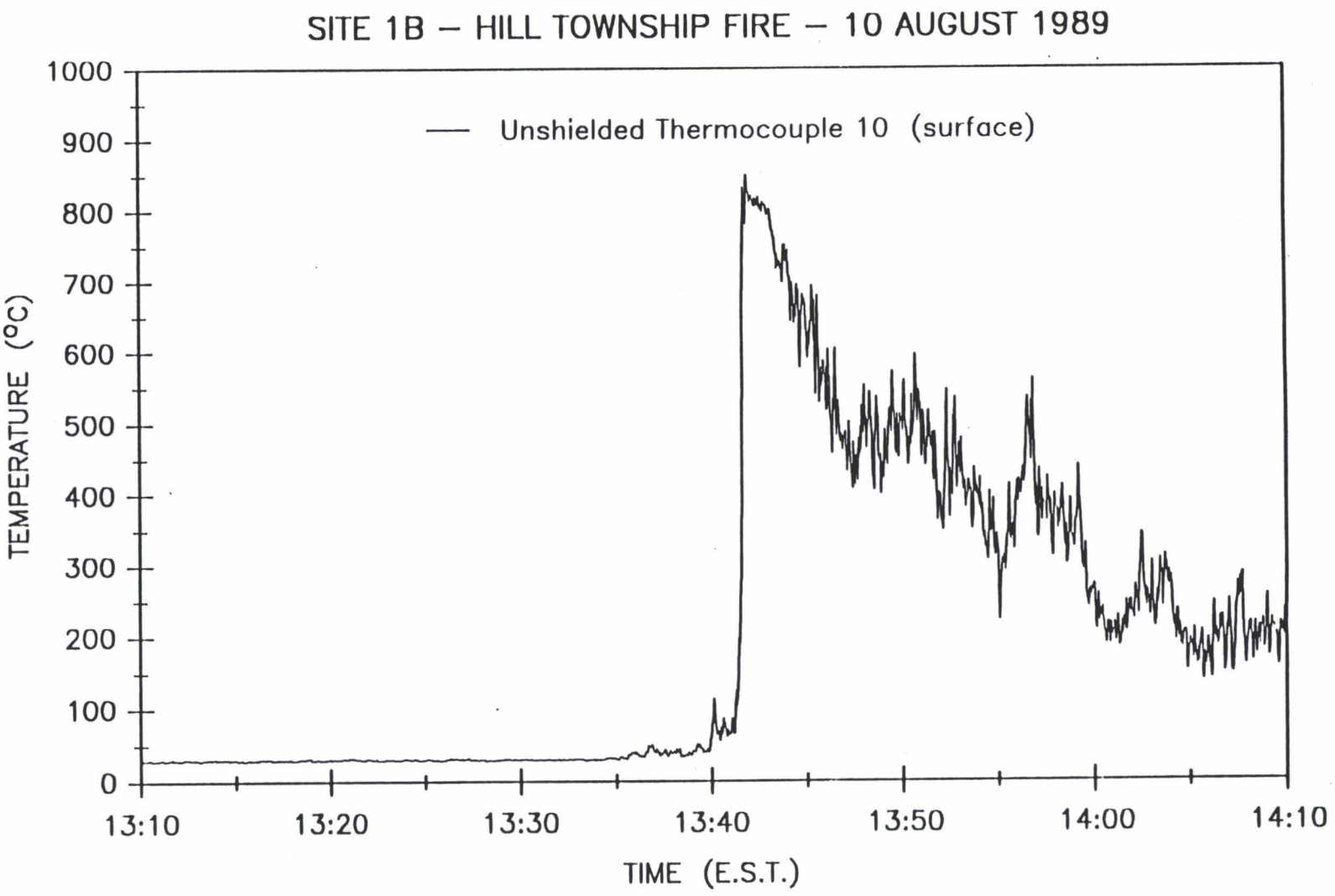

SITE 1B – HILL TOWNSHIP FIRE – 10 AUGUST 1989
Unshielded Thermocouple 5 (surface)
TEMPERATURE (°C)
1000
900
800
700
600
500
400
300
200
100
0
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)


SITE 1B – HILL TOWNSHIP FIRE – 10 AUGUST 1989
Unshielded Thermocouple 6 (surface)
TEMPERATURE (°C)
1000
900
800
700
600
500
400
300
200
100
0
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)

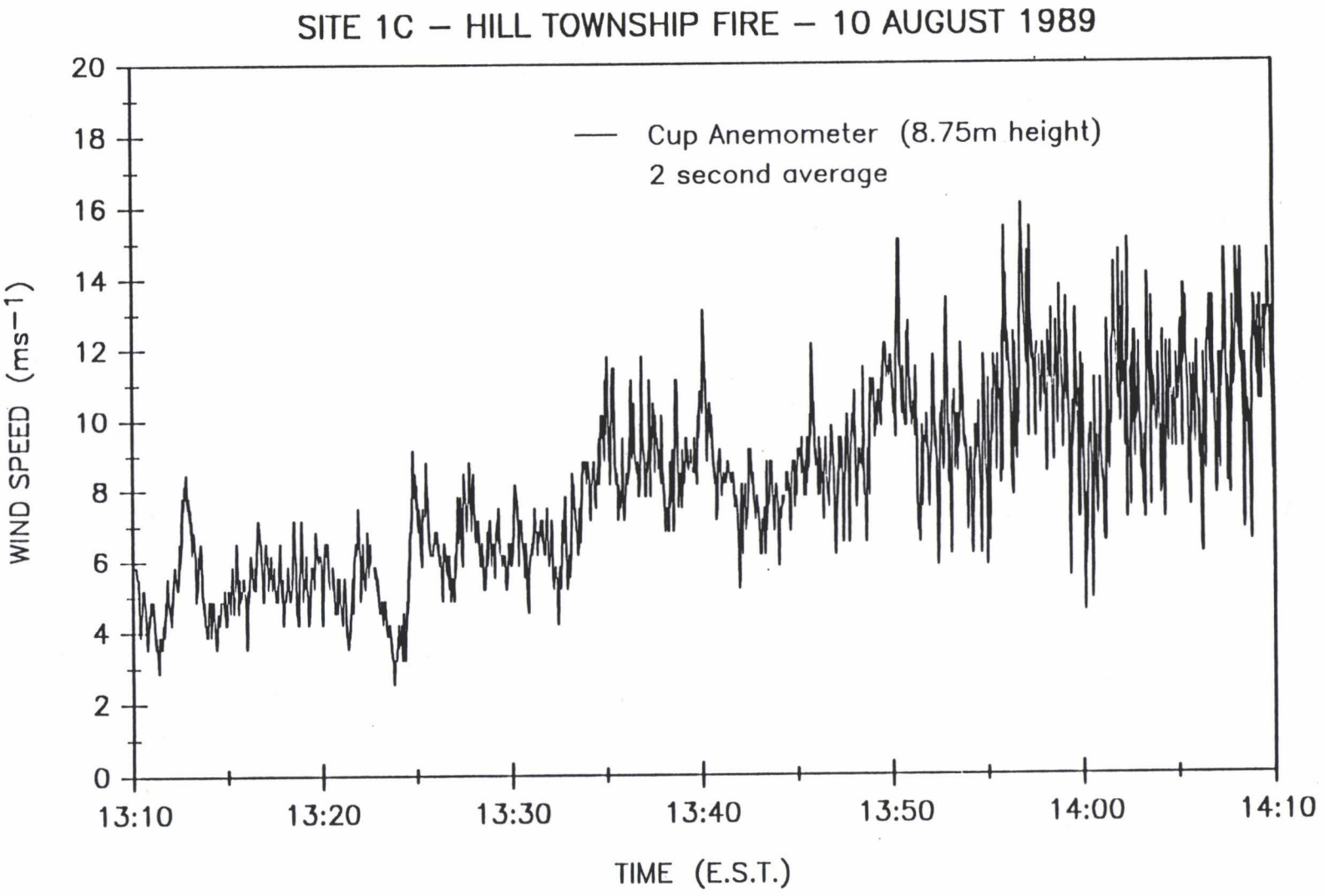

SITE 1B – HILL TOWNSHIP FIRE – 10 AUGUST 1989
Unshielded Thermocouple 7 (surface)
TEMPERATURE (°C)
1000
900
800
700
600
500
400
300
200
100
0
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)

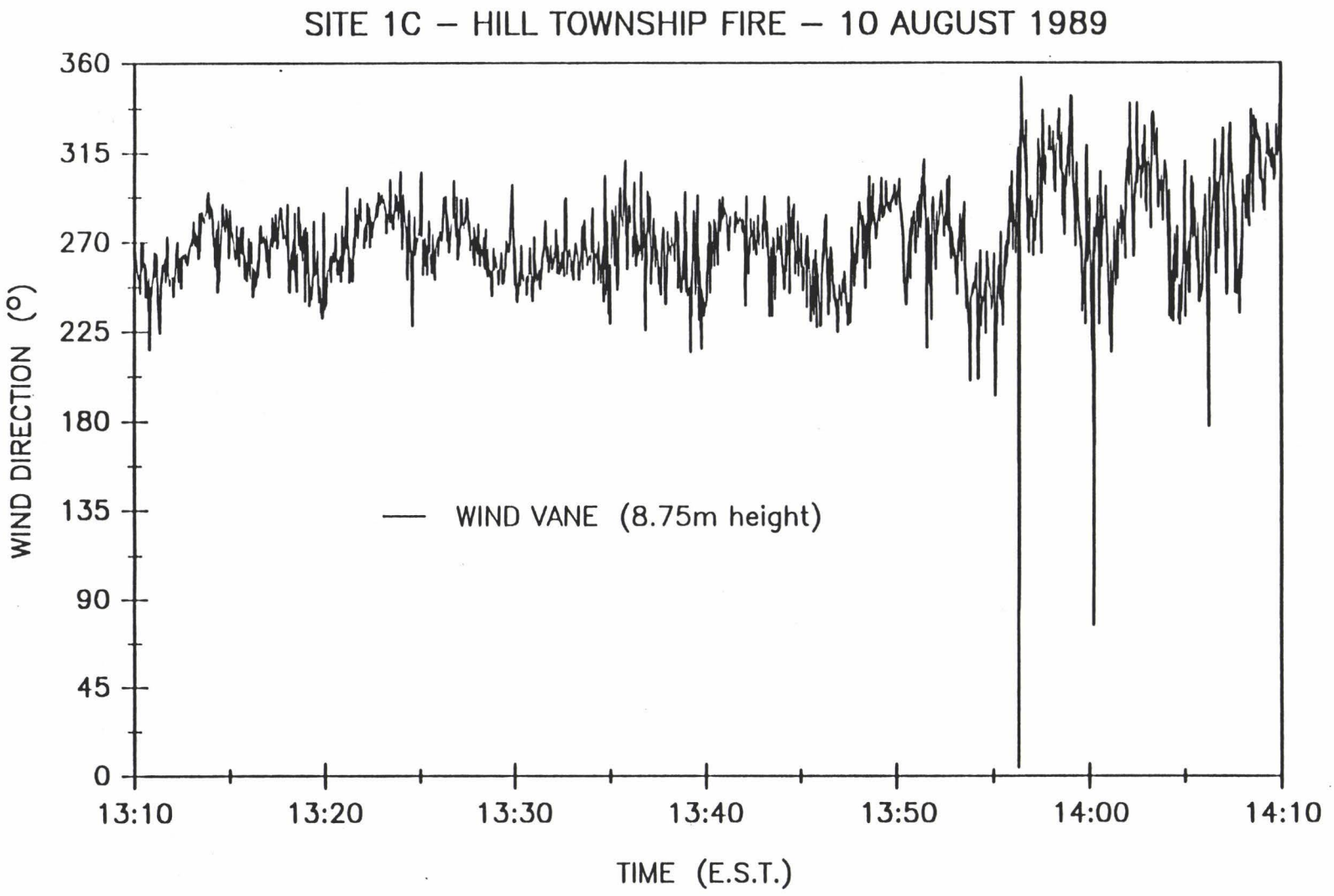

SITE 1B – HILL TOWNSHIP FIRE – 10 AUGUST 1989
Unshielded Thermocouple 8 (surface)
TEMPERATURE (°C)
1000
900
800
700
600
500
400
300
200
100
0
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)

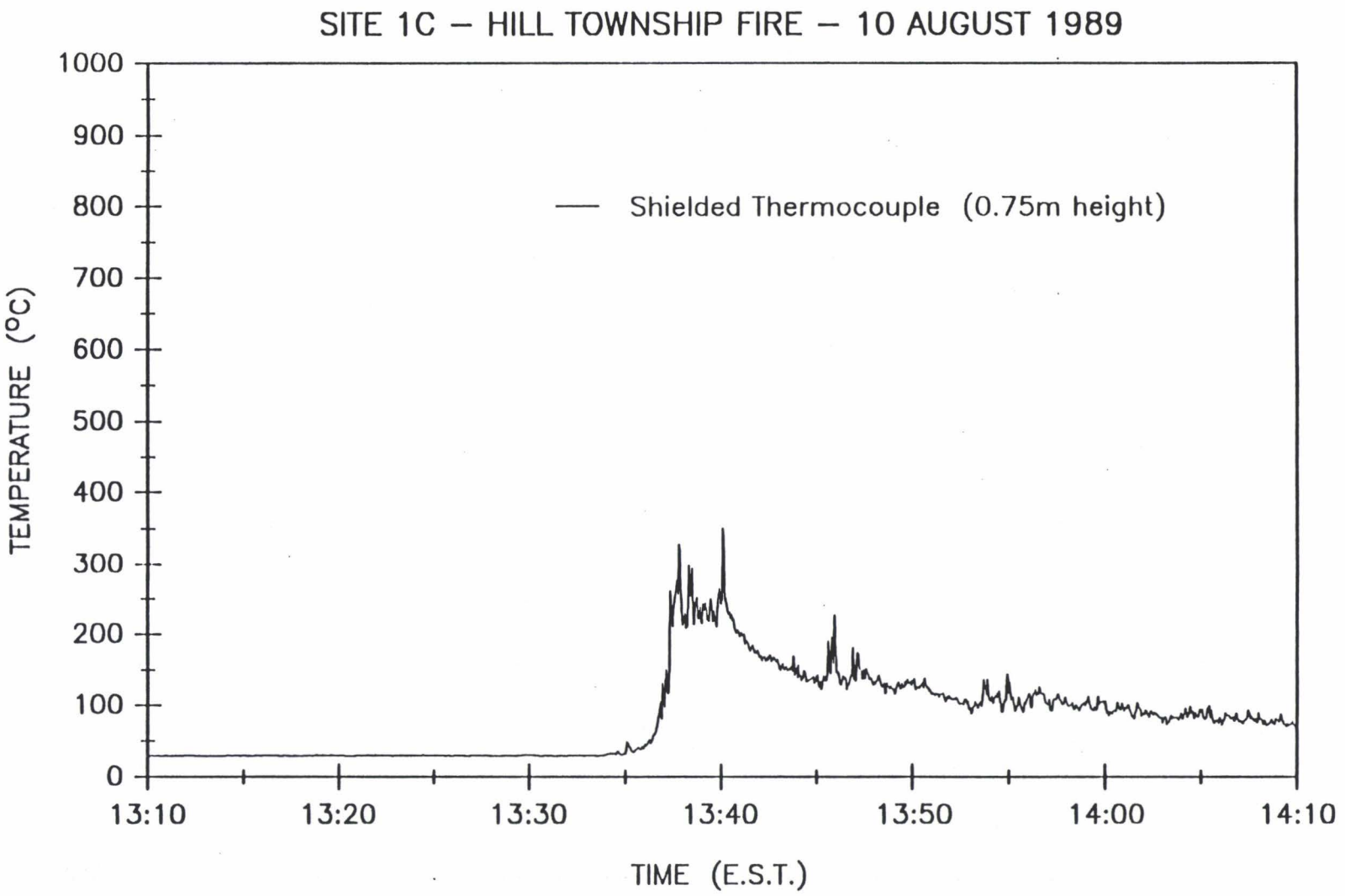

SITE 1B – HILL TOWNSHIP FIRE – 10 AUGUST 1989
Unshielded Thermocouple 9 (surface)
TEMPERATURE (°C)
1000
900
800
700
600
500
400
300
200
100
0
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)

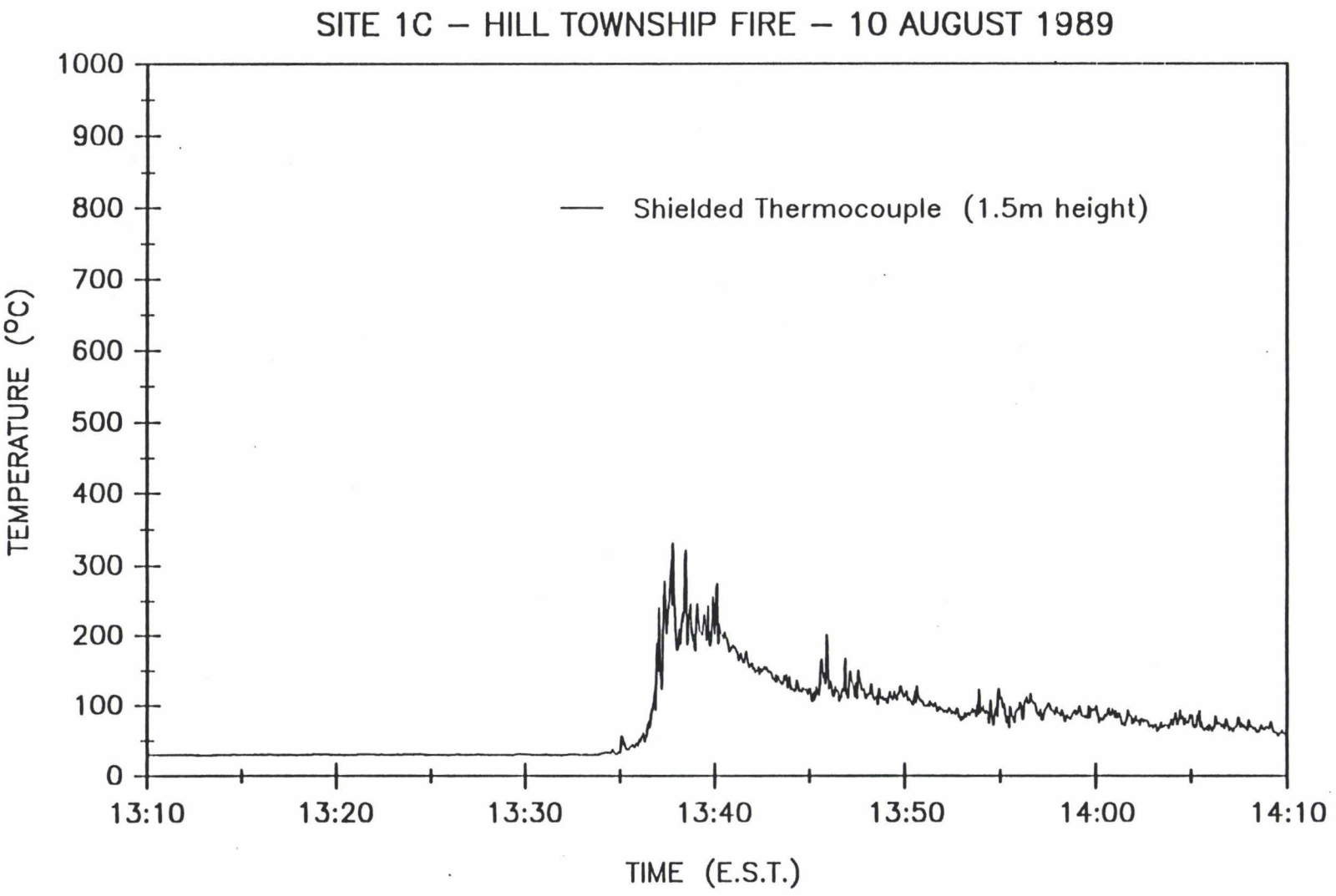

SITE 1B – HILL TOWNSHIP FIRE – 10 AUGUST 1989
Unshielded Thermocouple 10 (surface)
TEMPERATURE (°C)
1000
900
800
700
600
500
400
300
200
100
0
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)

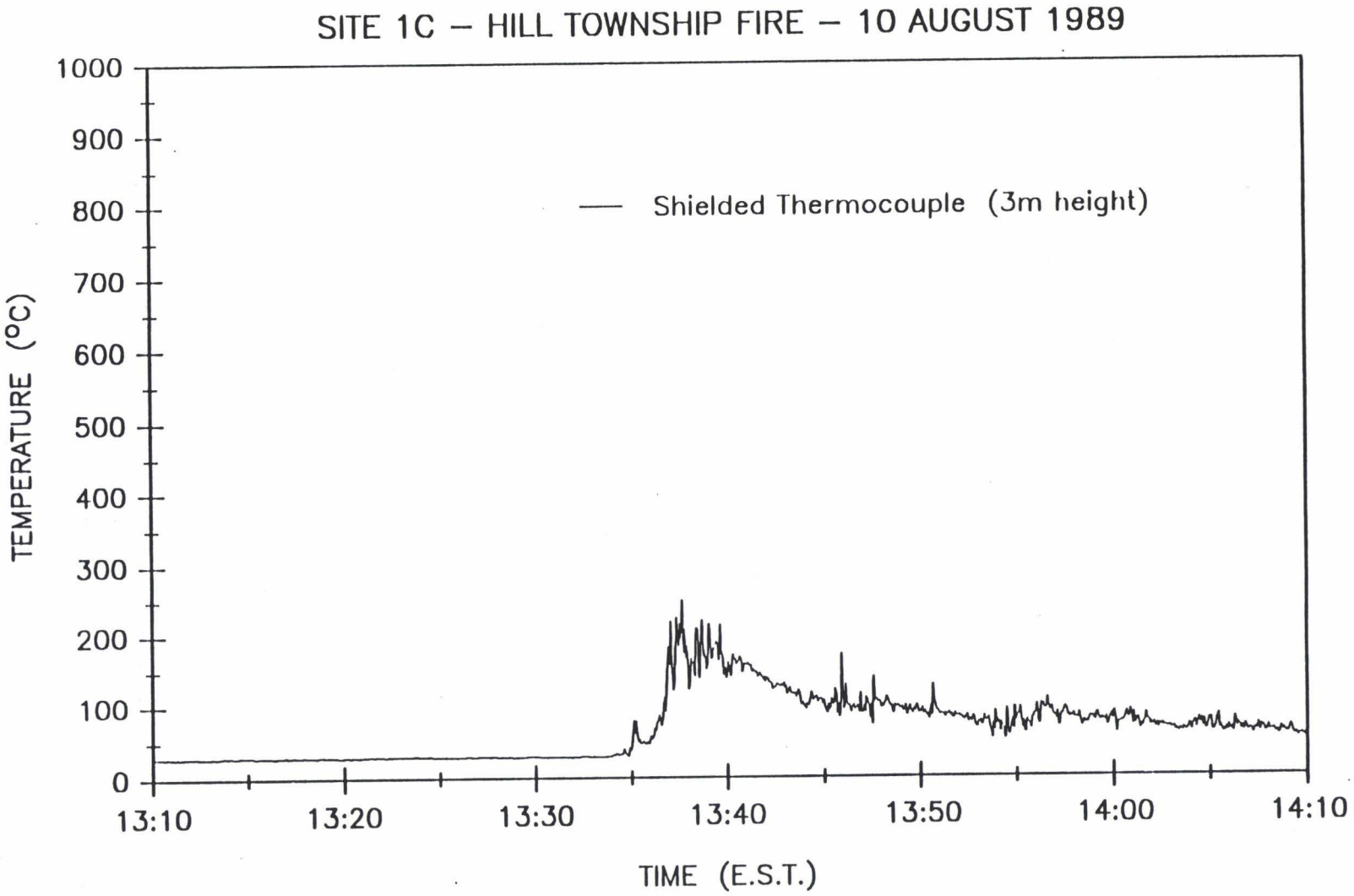
SITE 1 - TOWER C

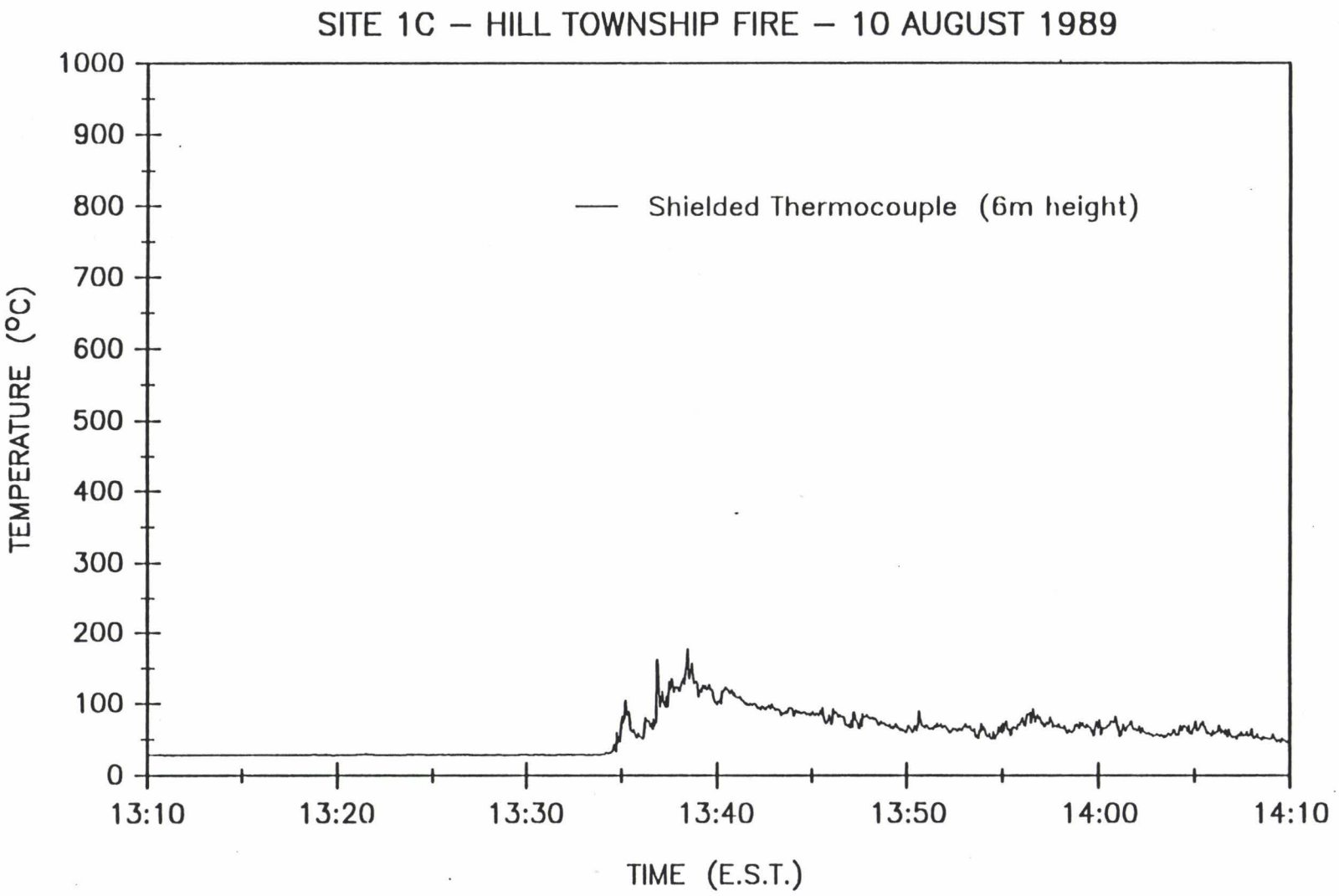

SITE 1C – HILL TOWNSHIP FIRE – 10 AUGUST 1989
Cup Anemometer (8.75m height)
2 second average
WIND SPEED (ms−1)
0
2
4
6
8
10
12
14
16
18
20
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)

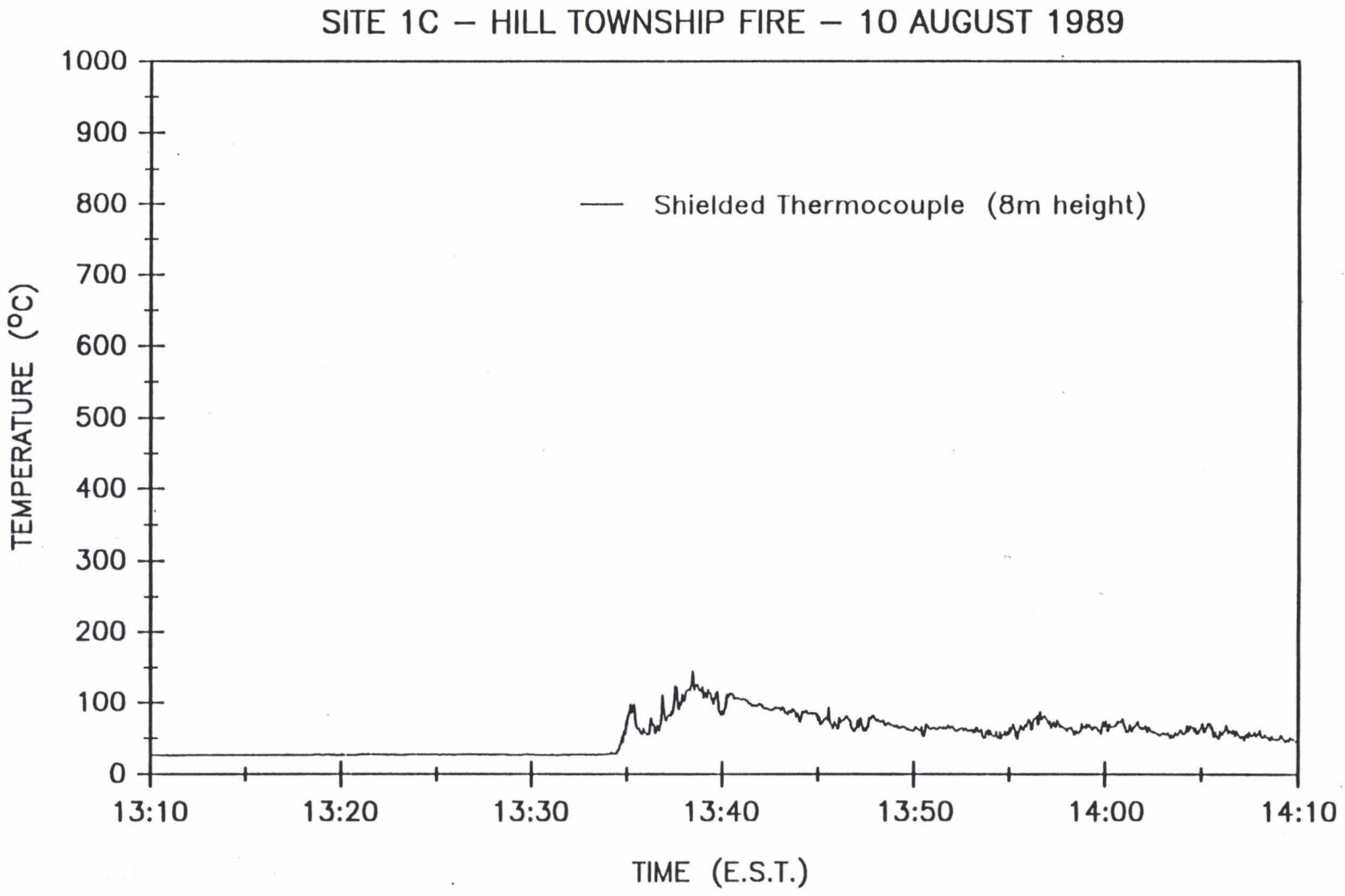

SITE 1C – HILL TOWNSHIP FIRE – 10 AUGUST 1989
WIND DIRECTION (°)
360
315
270
225
180
135
90
45
0
WIND VANE (8.75m height)
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)


SITE 1C – HILL TOWNSHIP FIRE – 10 AUGUST 1989
1000
900
800
700
600
500
400
300
200
100
0
TEMPERATURE (°C)
Shielded Thermocouple (0.75m height)
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)

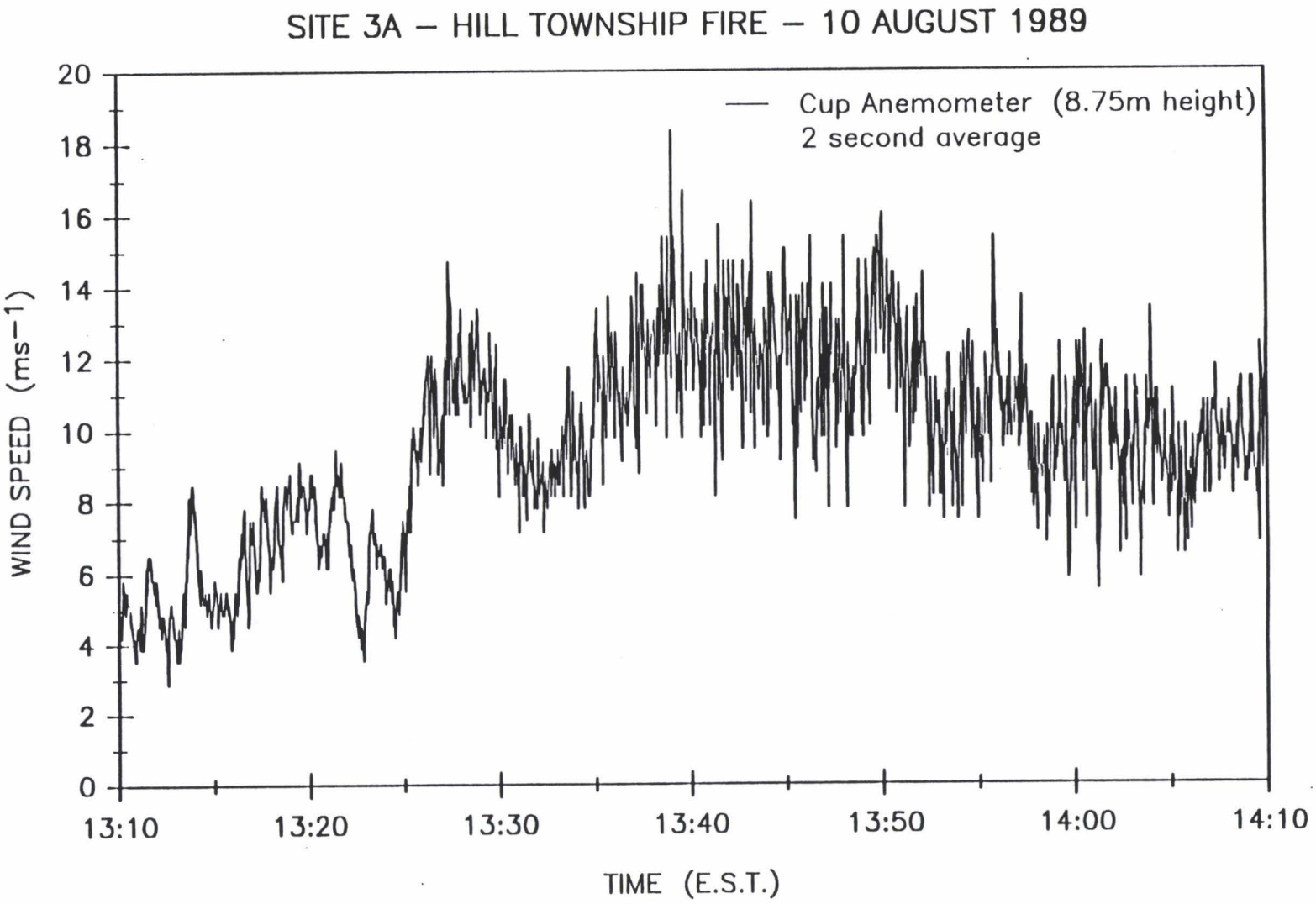

SITE 1C – HILL TOWNSHIP FIRE – 10 AUGUST 1989
Shielded Thermocouple (1.5m height)
TEMPERATURE (°C)
1000
900
800
700
600
500
400
300
200
100
0
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)

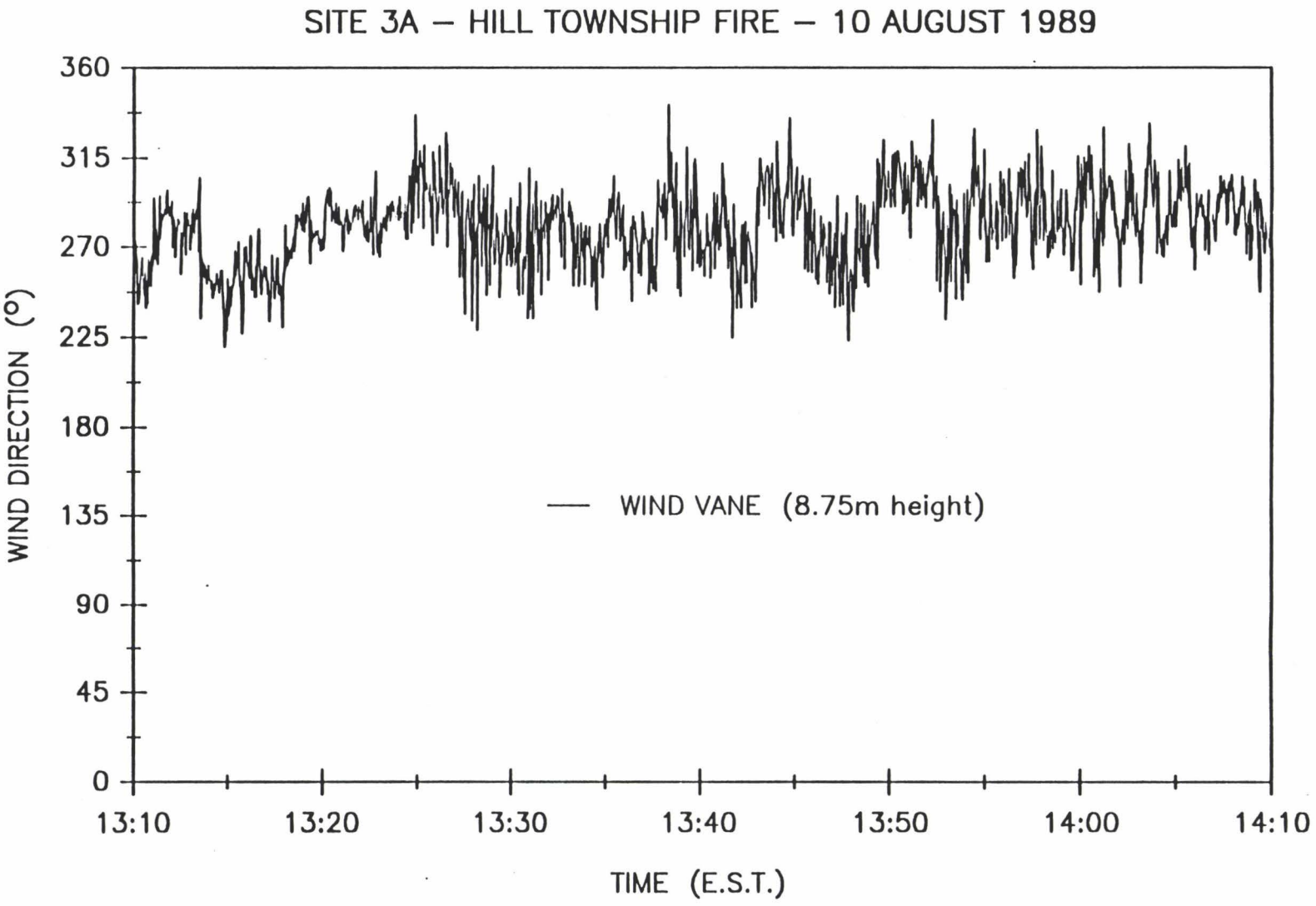

SITE 1C – HILL TOWNSHIP FIRE – 10 AUGUST 1989
Shielded Thermocouple (3m height)
TEMPERATURE (°C)
1000
900
800
700
600
500
400
300
200
100
0
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)

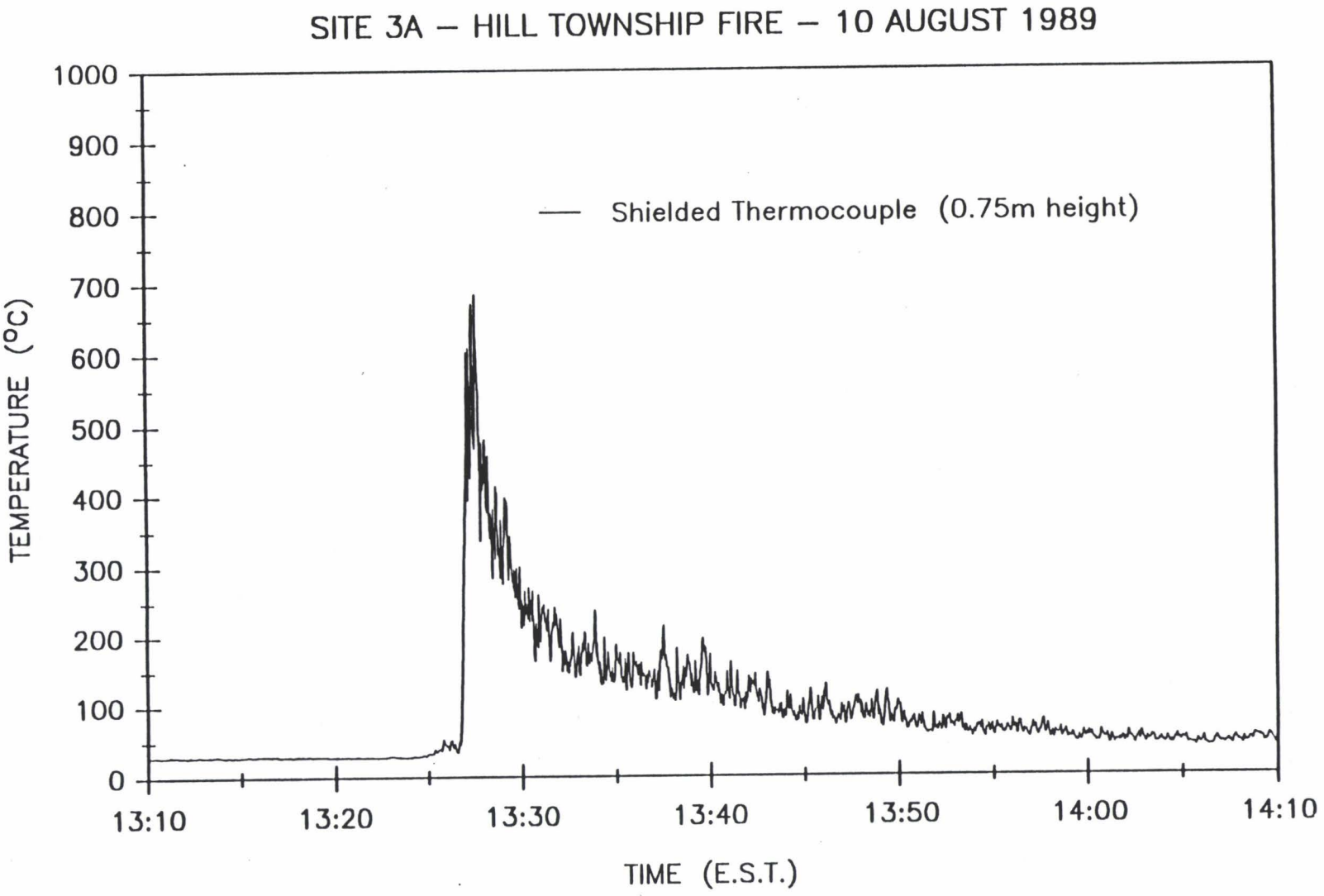

SITE 1C – HILL TOWNSHIP FIRE – 10 AUGUST 1989
Shielded Thermocouple (6m height)
TEMPERATURE (°C)
1000
900
800
700
600
500
400
300
200
100
0
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)

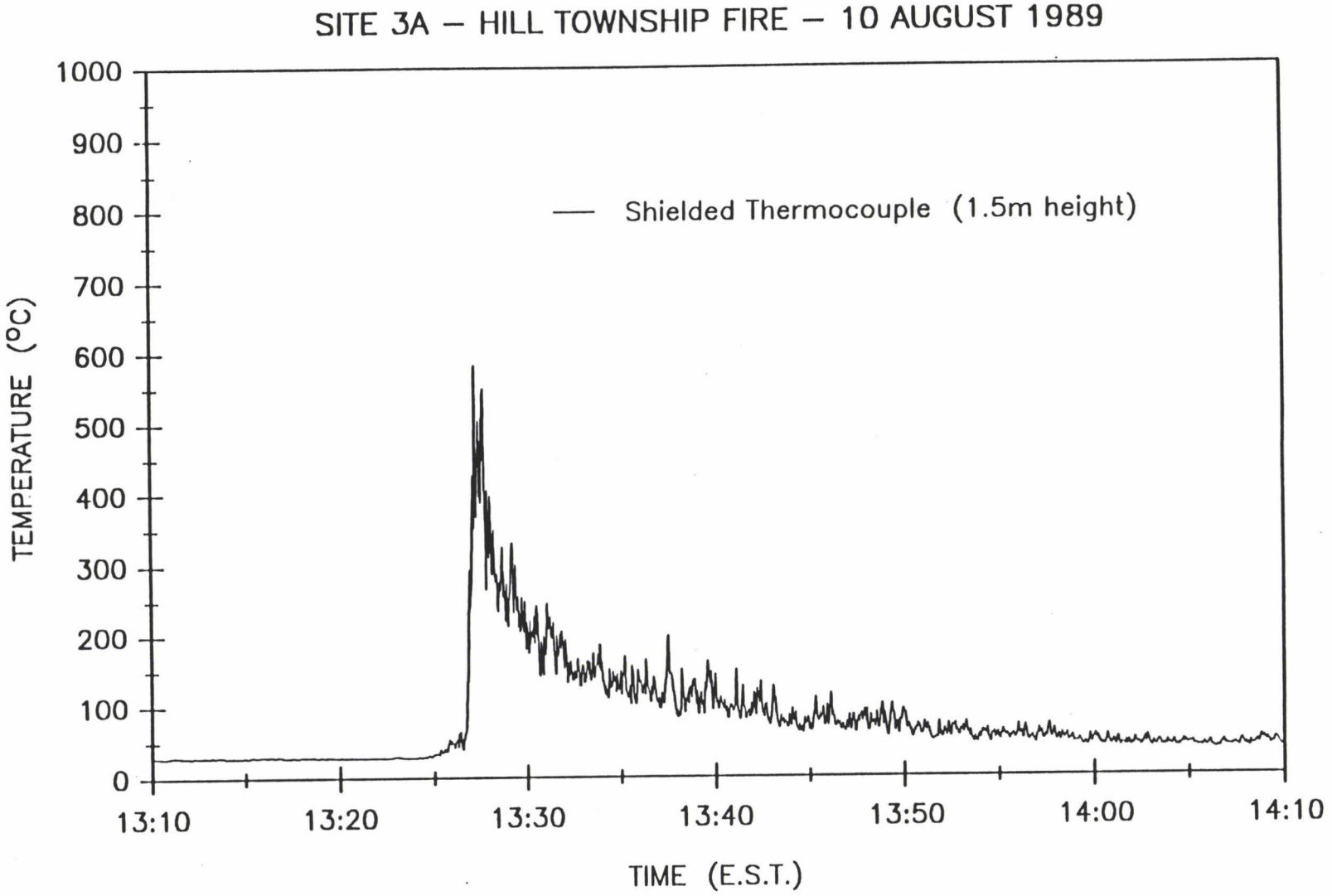

SITE 1C – HILL TOWNSHIP FIRE – 10 AUGUST 1989
Shielded Thermocouple (8m height)
TEMPERATURE (°C)
1000
900
800
700
600
500
400
300
200
100
0
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)

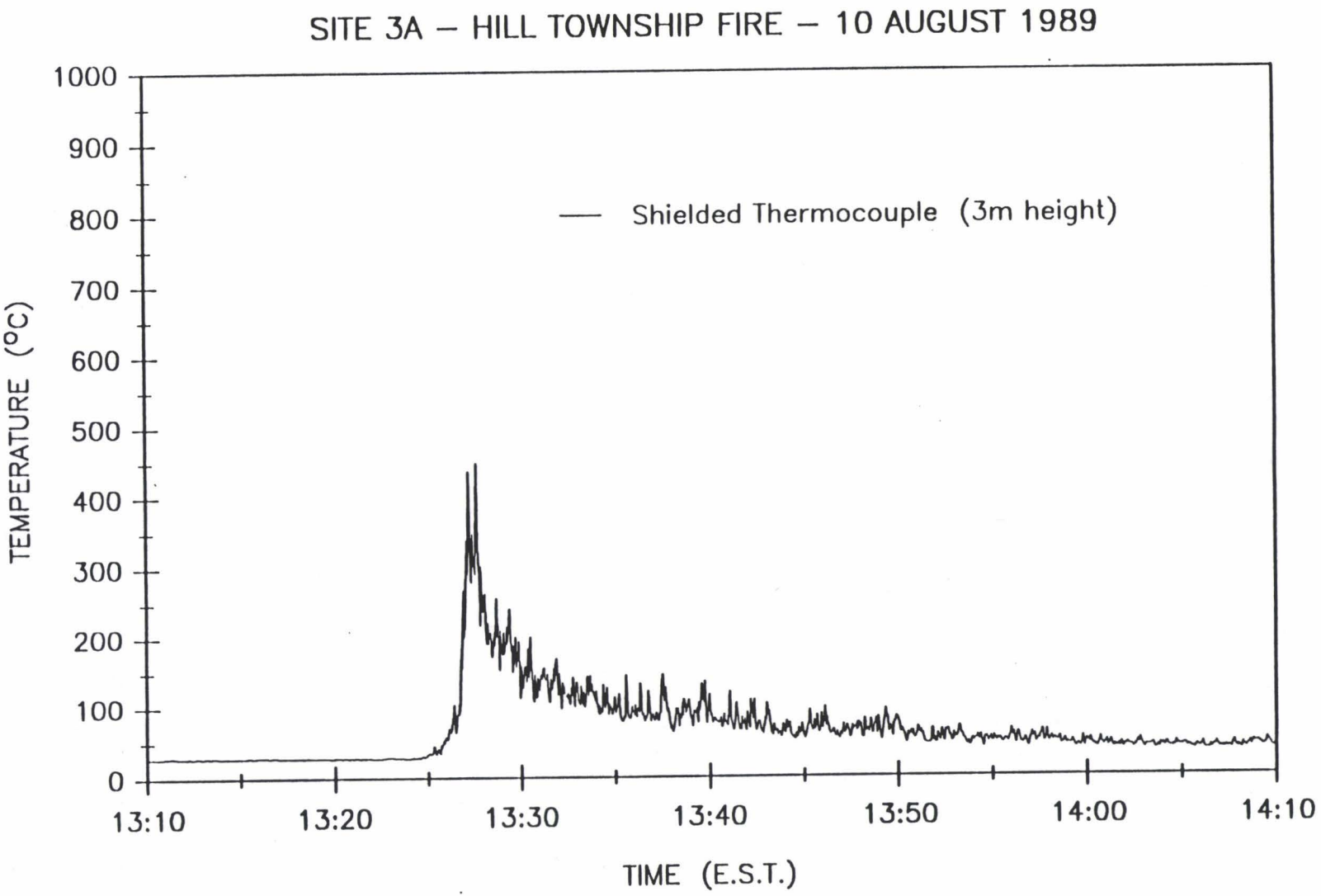
SITE 3 - TOWER A

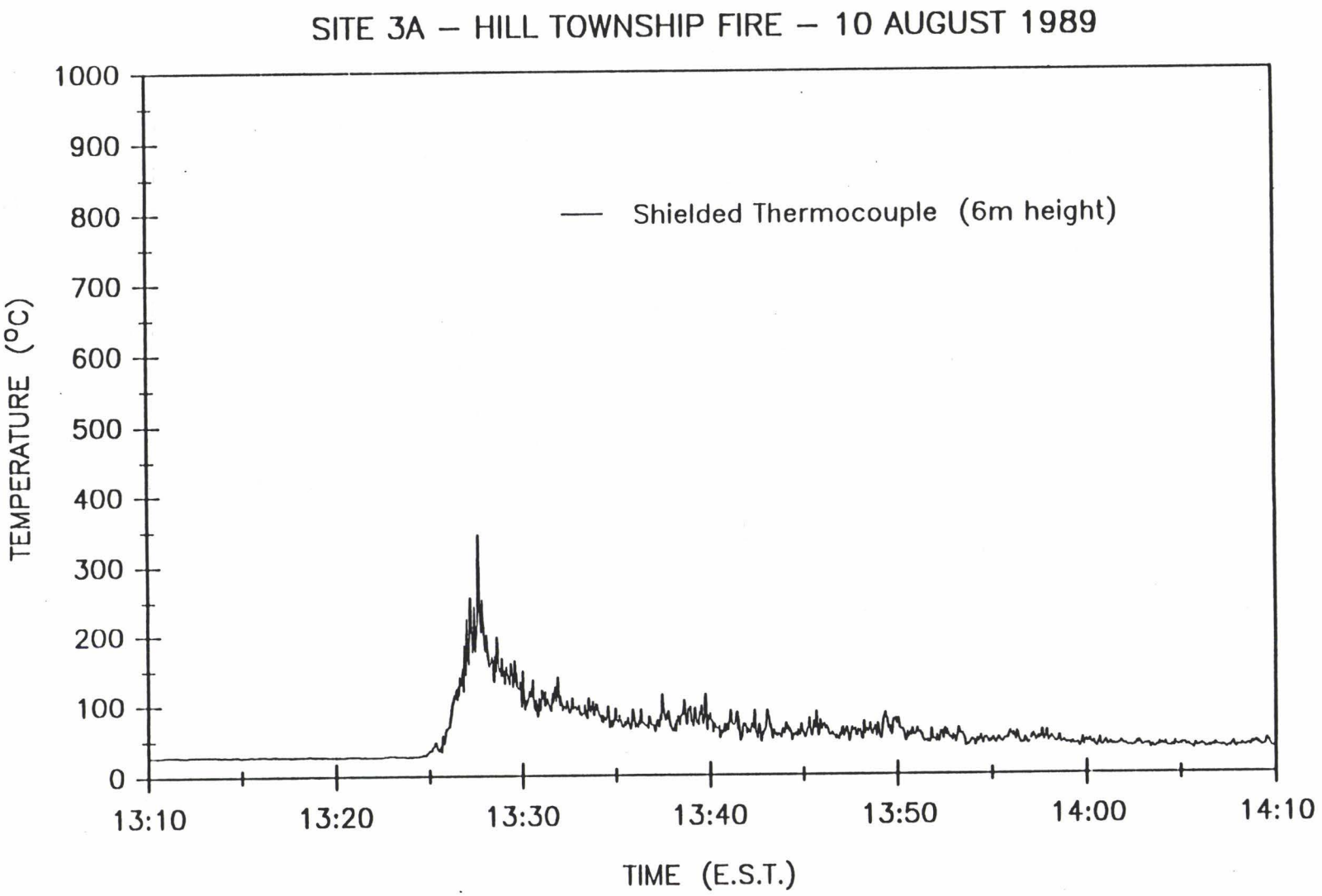

SITE 3A – HILL TOWNSHIP FIRE – 10 AUGUST 1989
Cup Anemometer (8.75m height)
2 second average
WIND SPEED (ms⁻¹)
20
18
16
14
12
10
8
6
4
2
0
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)

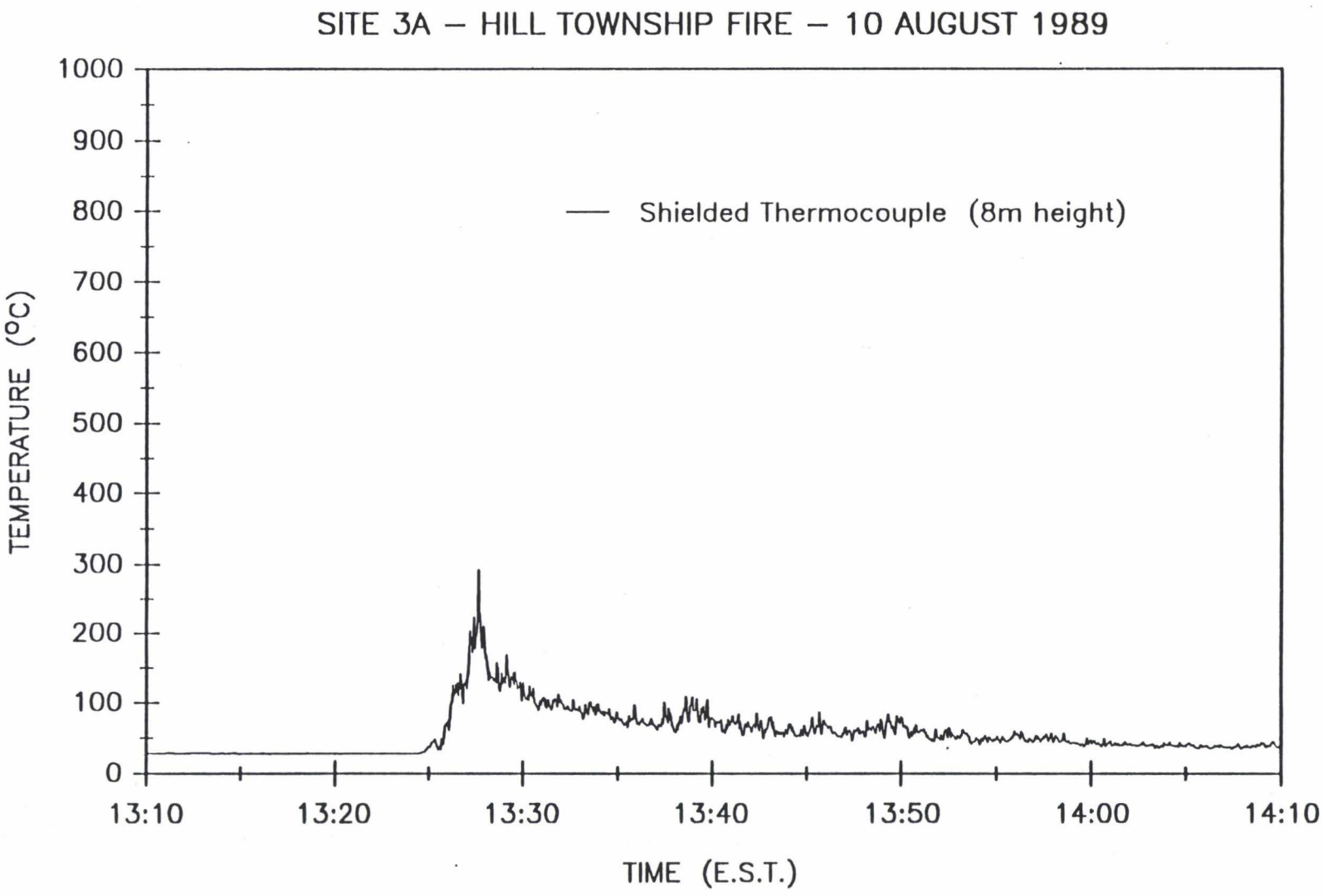

SITE 3A – HILL TOWNSHIP FIRE – 10 AUGUST 1989
WIND DIRECTION (°)
360
315
270
225
180
135
90
45
0
WIND VANE (8.75m height)
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)


SITE 3A – HILL TOWNSHIP FIRE – 10 AUGUST 1989
Shielded Thermocouple (0.75m height)
TEMPERATURE (°C)
1000
900
800
700
600
500
400
300
200
100
0
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)

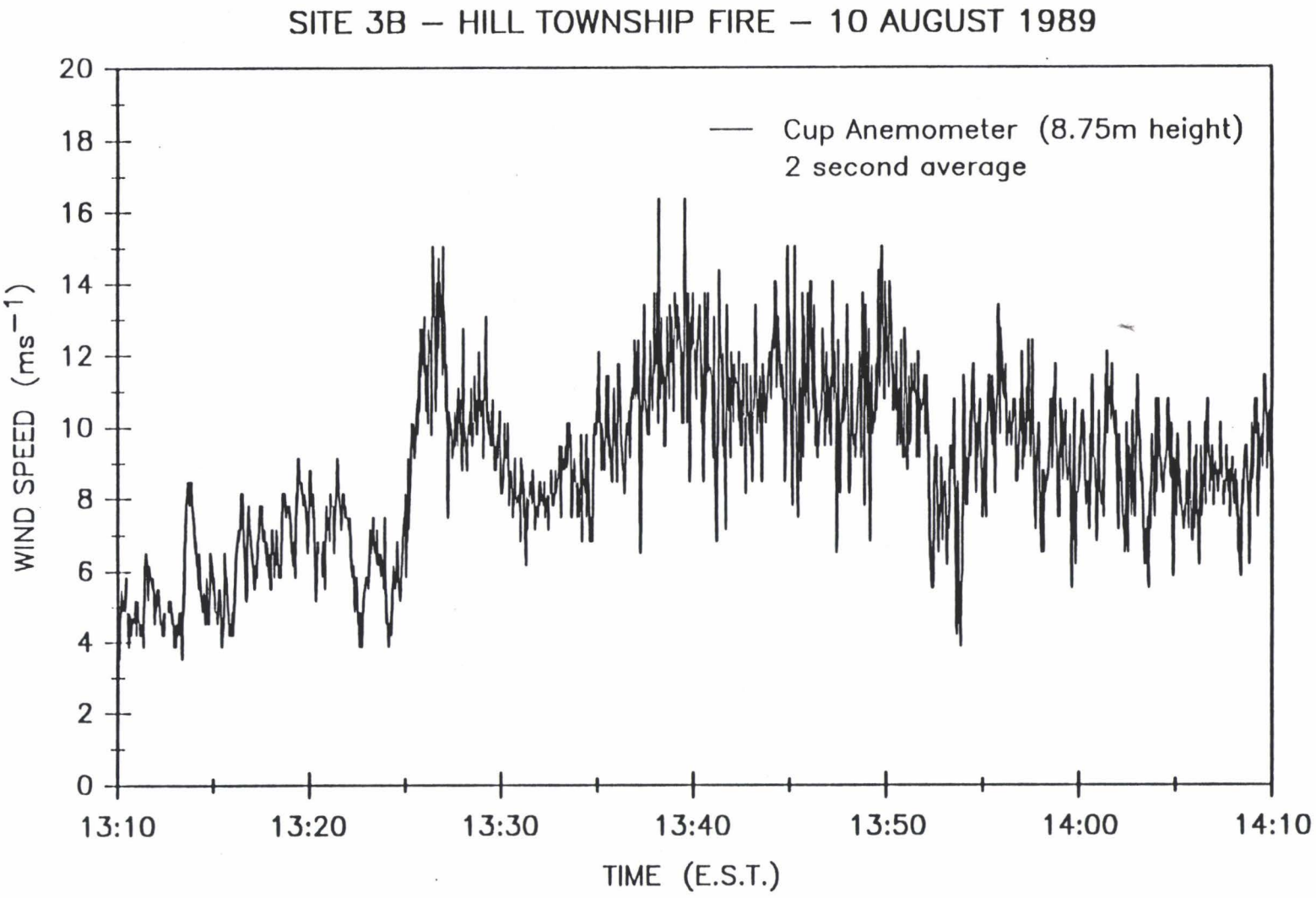

SITE 3A – HILL TOWNSHIP FIRE – 10 AUGUST 1989
Shielded Thermocouple (1.5m height)
TEMPERATURE (°C)
1000
900
800
700
600
500
400
300
200
100
0
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)

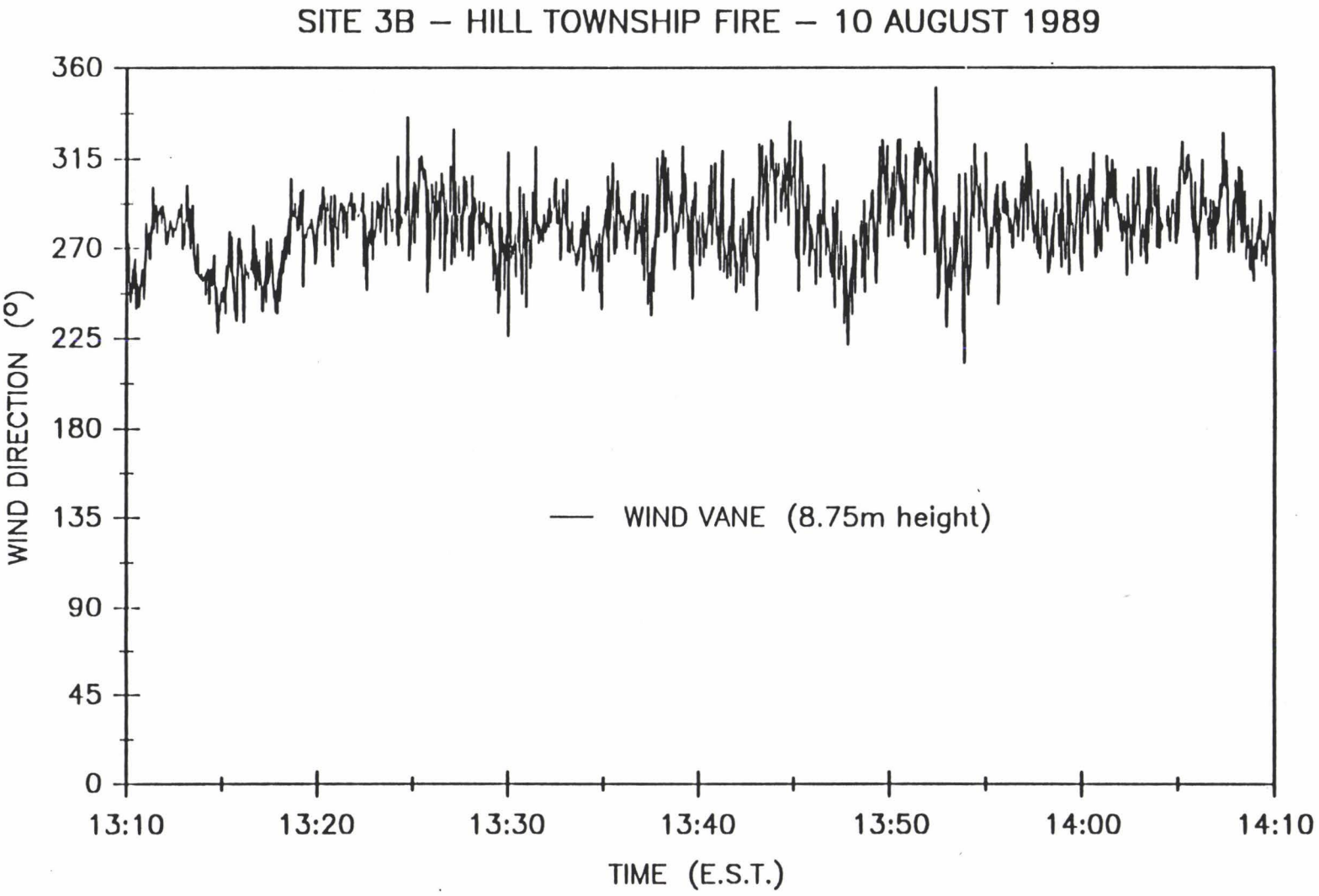

SITE 3A – HILL TOWNSHIP FIRE – 10 AUGUST 1989
Shielded Thermocouple (3m height)
TEMPERATURE (°C)
1000
900
800
700
600
500
400
300
200
100
0
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)

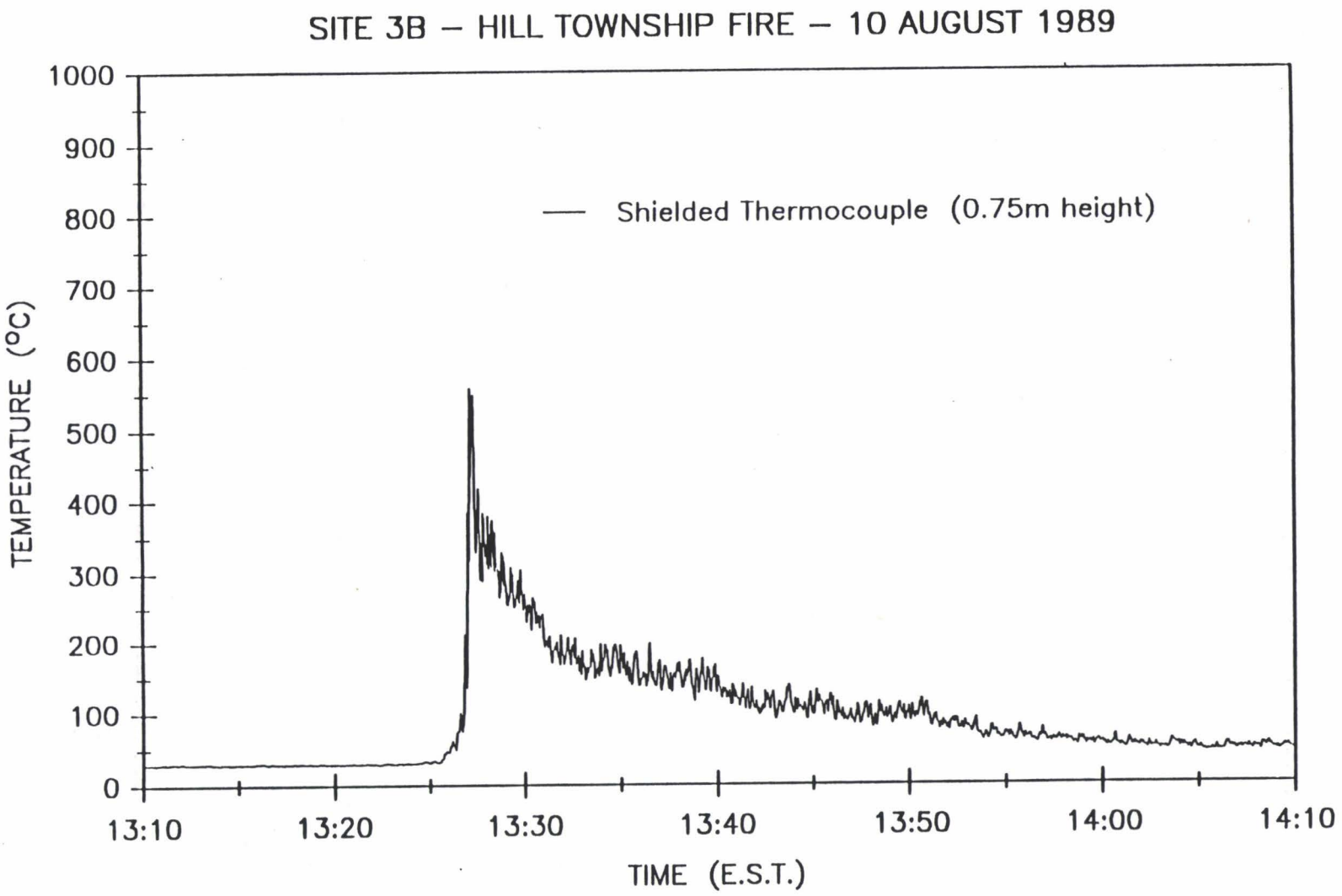

SITE 3A – HILL TOWNSHIP FIRE – 10 AUGUST 1989
Shielded Thermocouple (6m height)
TEMPERATURE (°C)
1000
900
800
700
600
500
400
300
200
100
0
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)

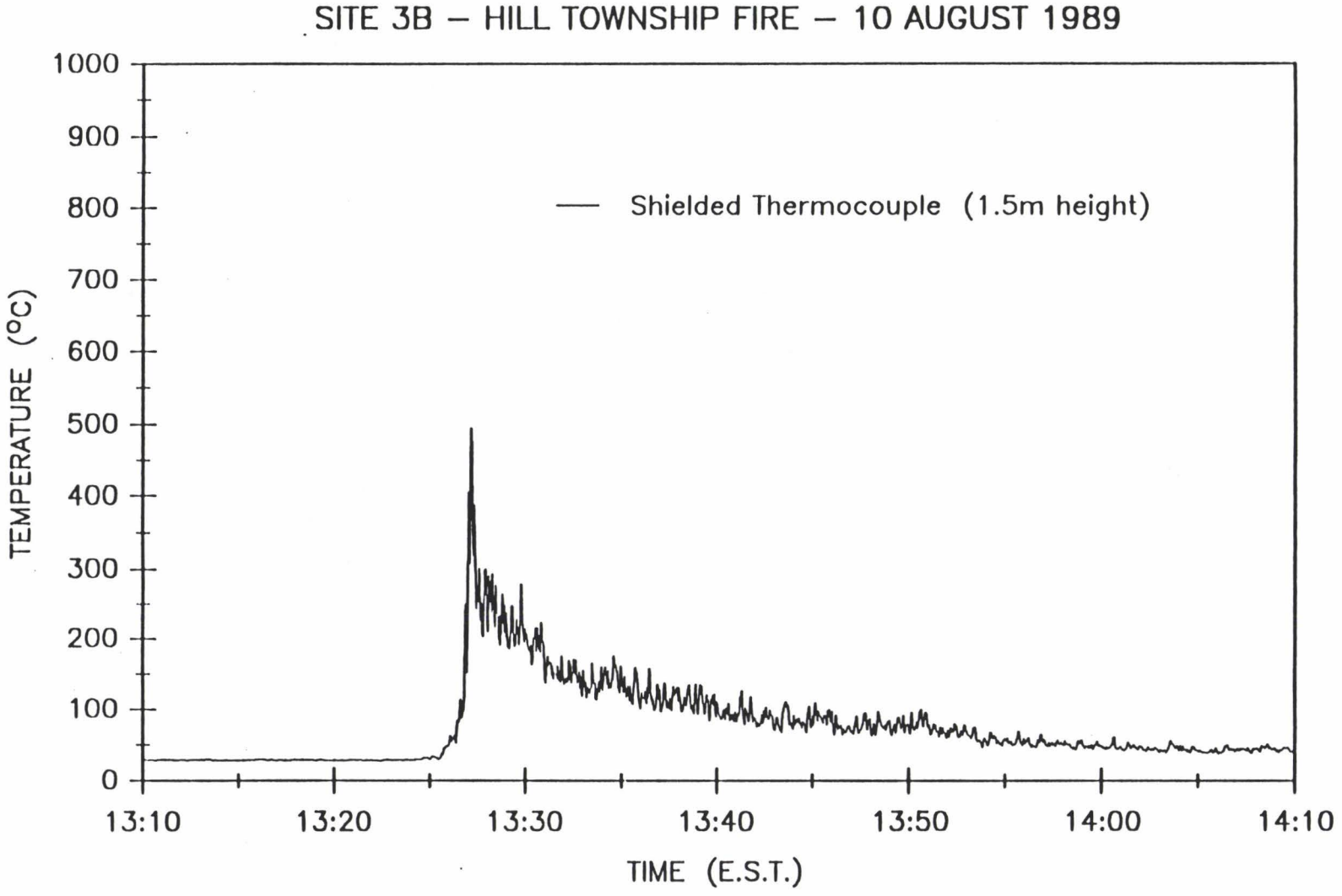

SITE 3A – HILL TOWNSHIP FIRE – 10 AUGUST 1989
Shielded Thermocouple (8m height)
TEMPERATURE (°C)
1000
900
800
700
600
500
400
300
200
100
0
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)

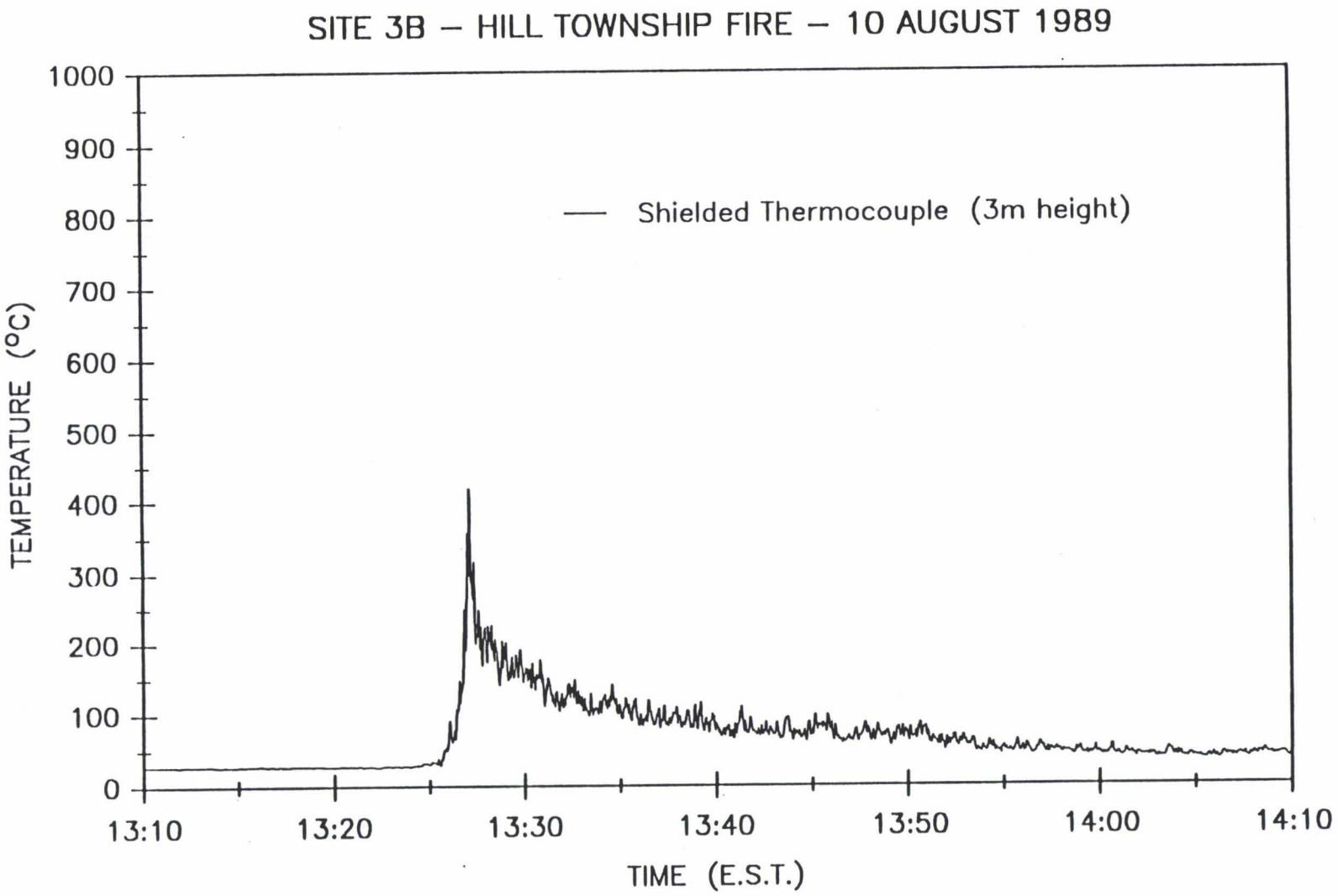
SITE 3 - TOWER B

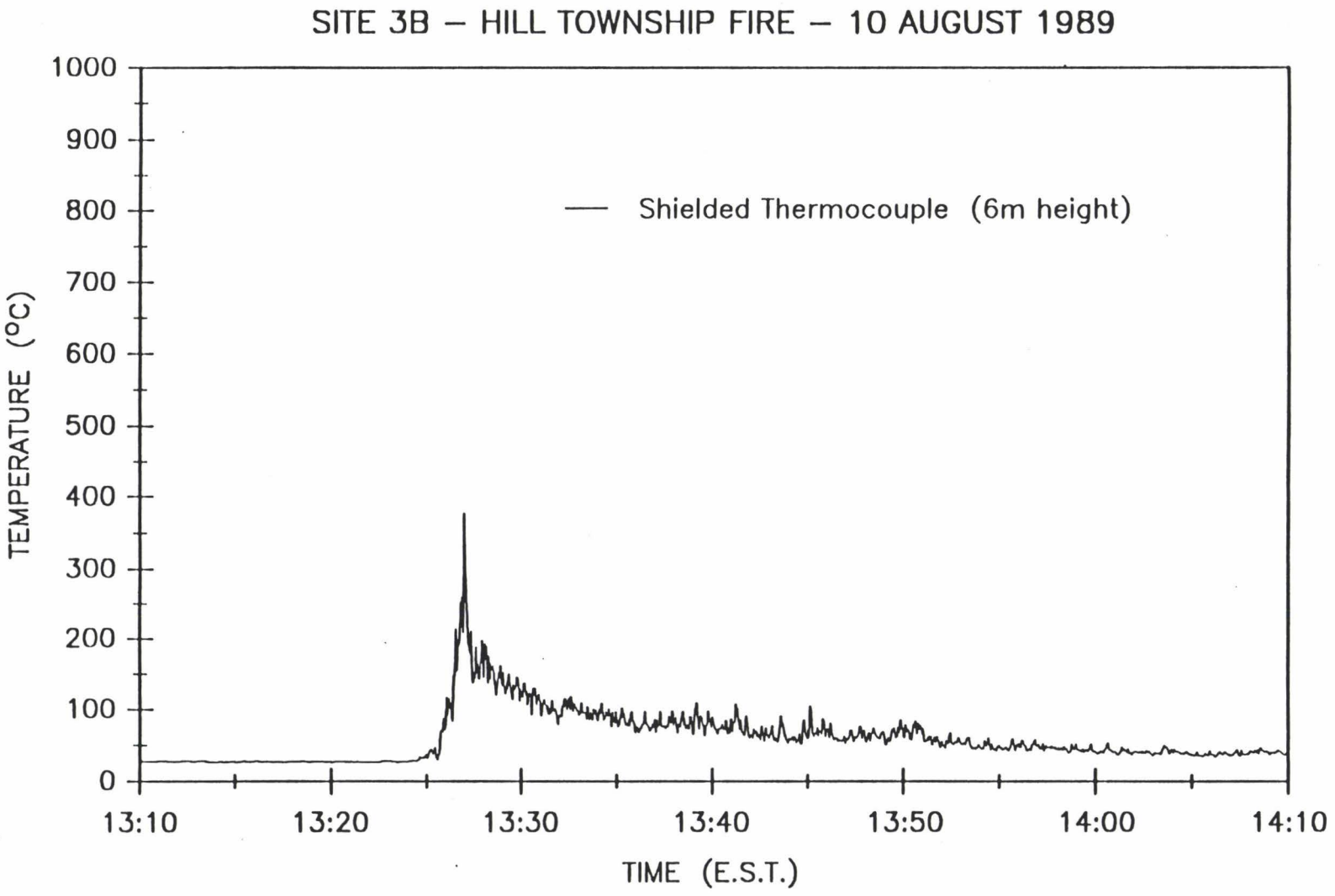

SITE 3B – HILL TOWNSHIP FIRE – 10 AUGUST 1989
Cup Anemometer (8.75m height)
2 second average
WIND SPEED (ms^{-1})
20
18
16
14
12
10
8
6
4
2
0
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)

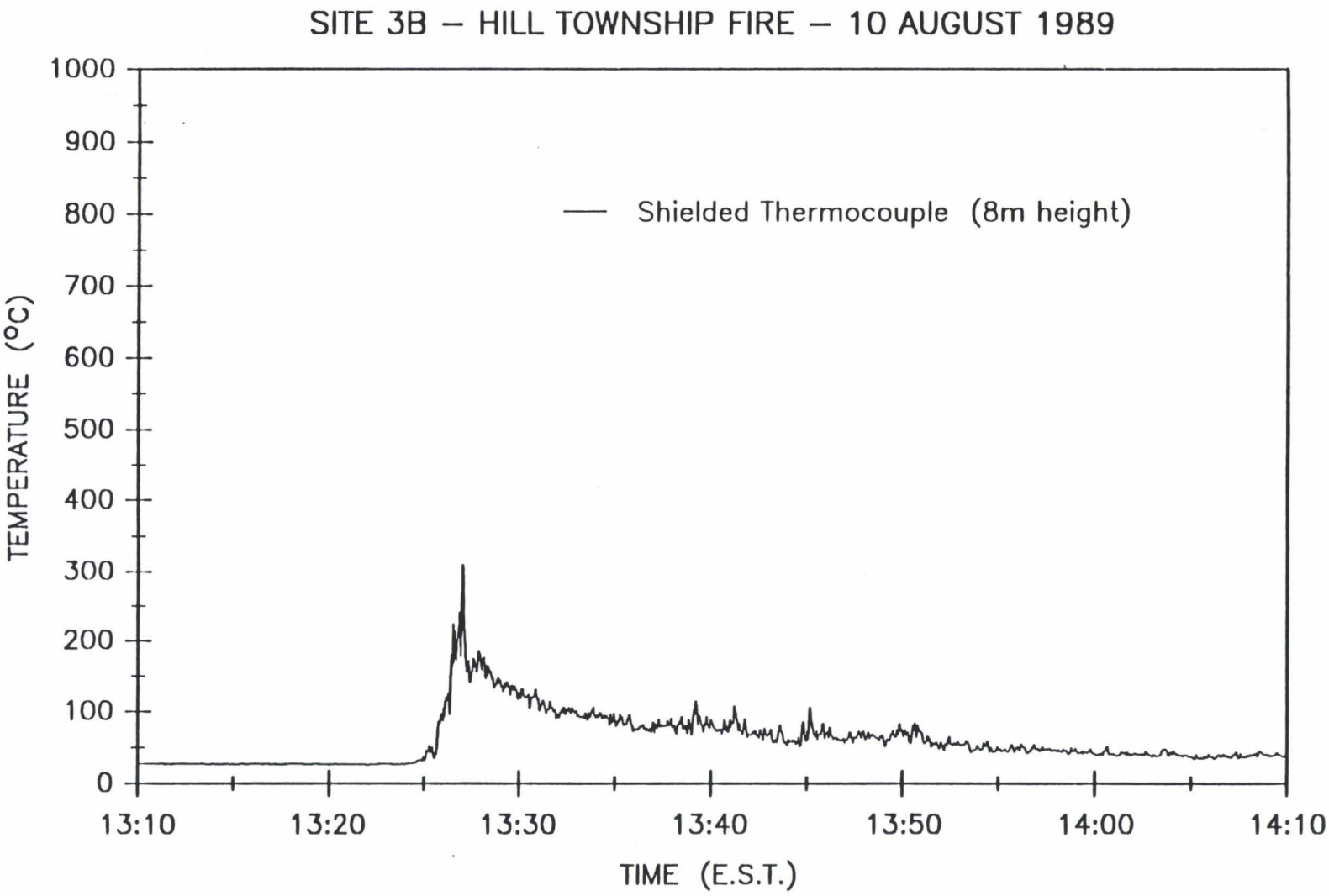

SITE 3B – HILL TOWNSHIP FIRE – 10 AUGUST 1989
360
315
270
225
180
135
90
45
0
WIND DIRECTION (°)
WIND VANE (8.75m height)
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)


SITE 3B – HILL TOWNSHIP FIRE – 10 AUGUST 1989
Shielded Thermocouple (0.75m height)
TEMPERATURE (°C)
1000
900
800
700
600
500
400
300
200
100
0
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)

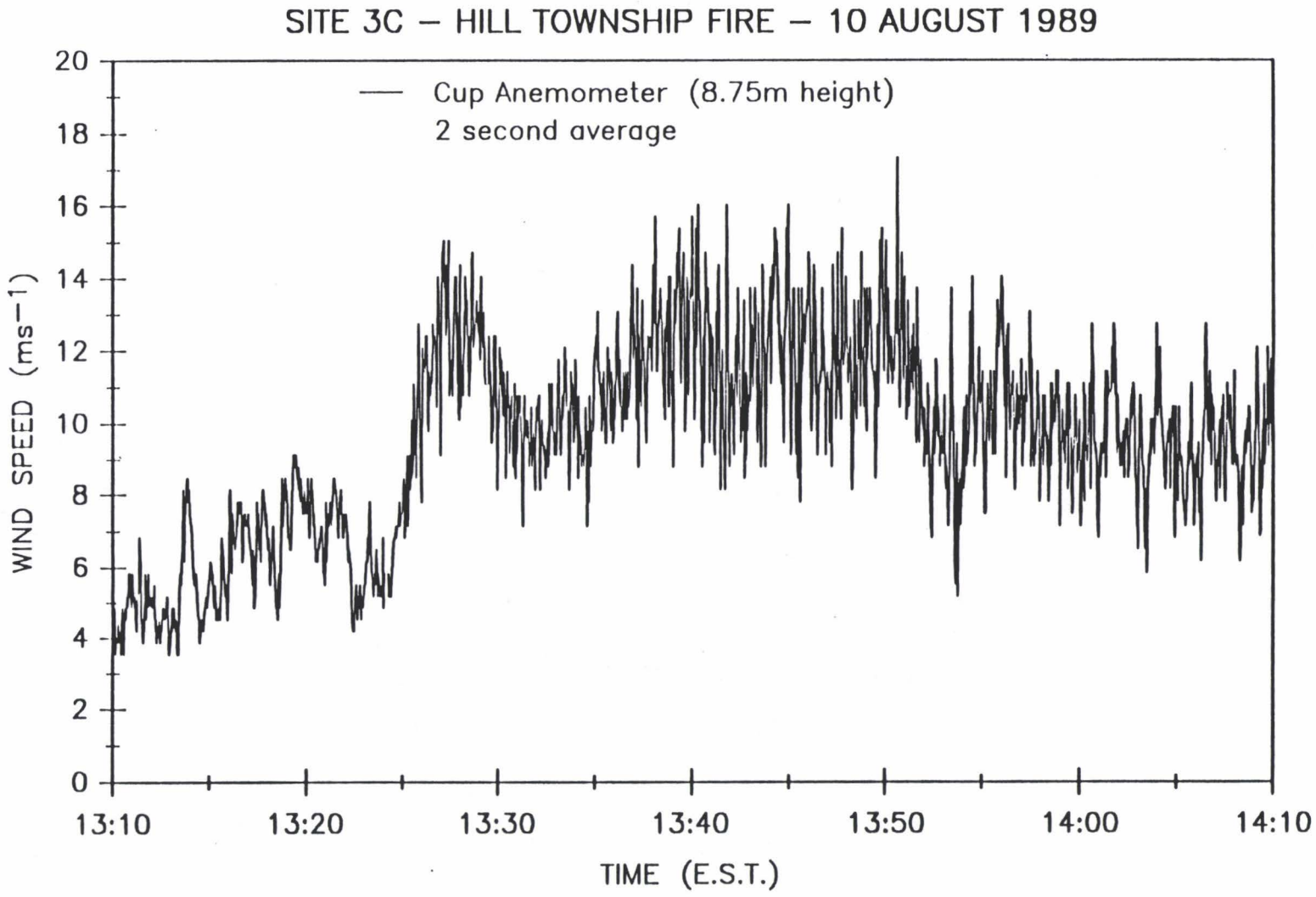

SITE 3B – HILL TOWNSHIP FIRE – 10 AUGUST 1989
Shielded Thermocouple (1.5m height)
TEMPERATURE (°C)
1000
900
800
700
600
500
400
300
200
100
0
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)

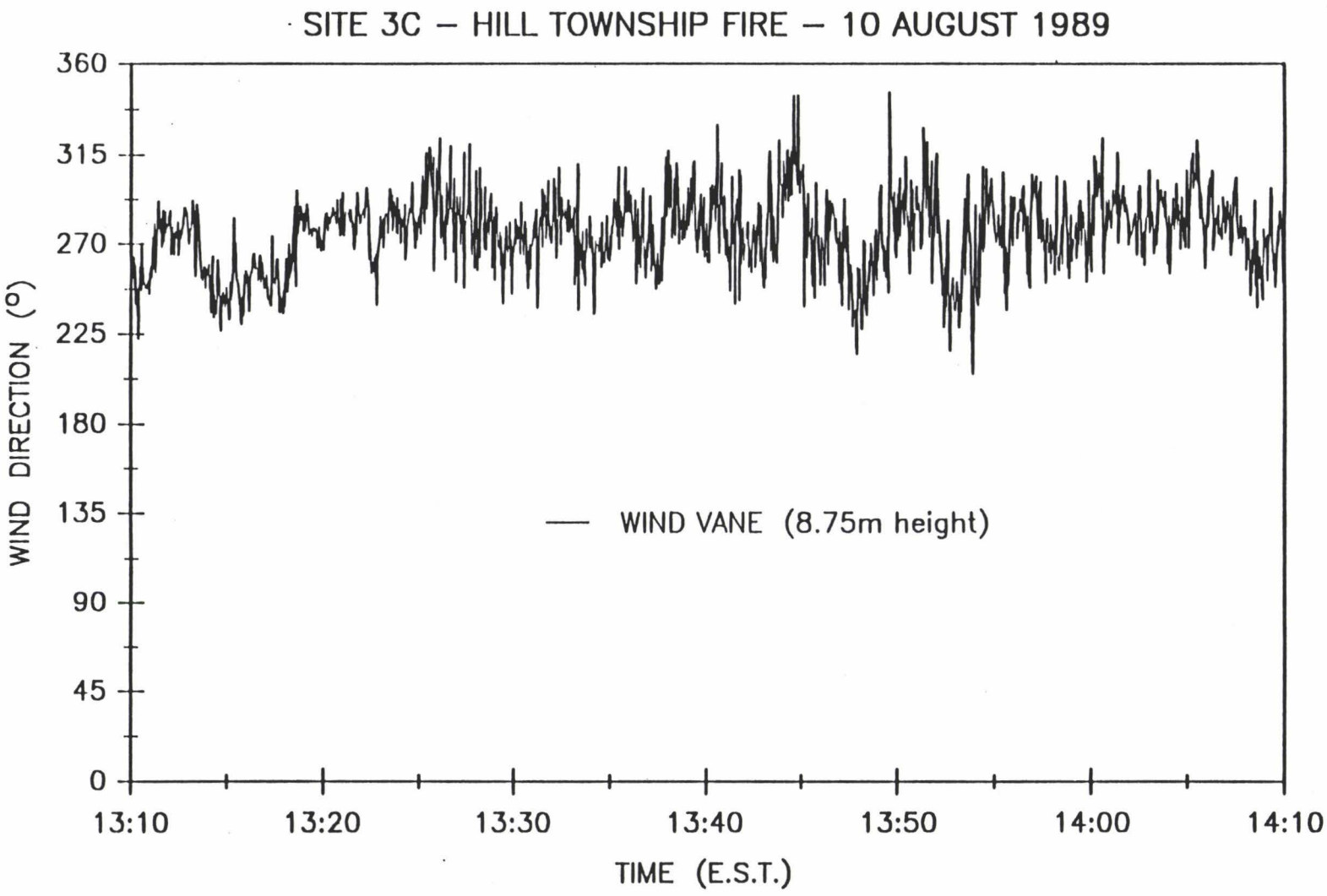

SITE 3B – HILL TOWNSHIP FIRE – 10 AUGUST 1989
Shielded Thermocouple (3m height)
TEMPERATURE (°C)
1000
900
800
700
600
500
400
300
200
100
0
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)

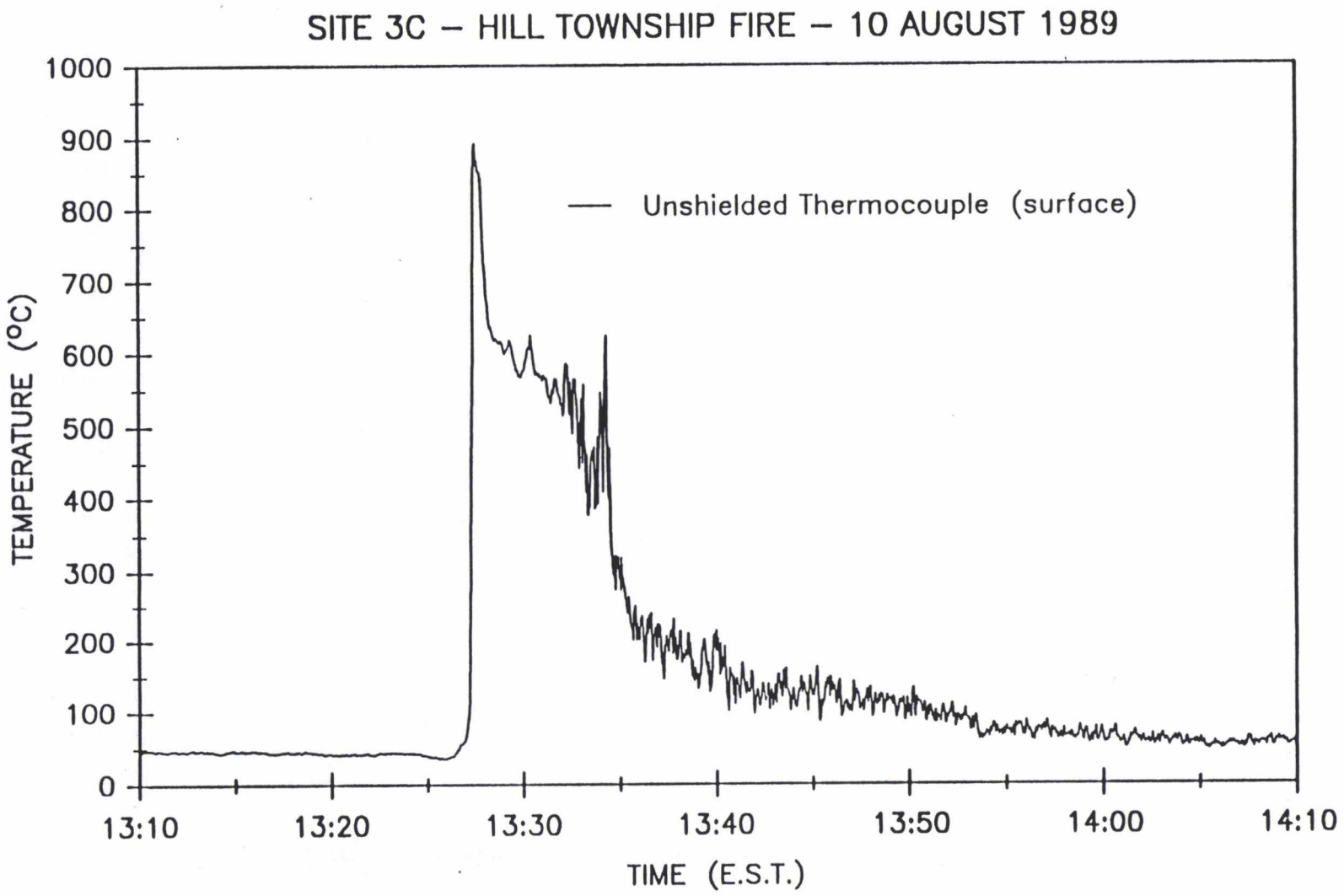

SITE 3B – HILL TOWNSHIP FIRE – 10 AUGUST 1989
Shielded Thermocouple (6m height)
TEMPERATURE (°C)
1000
900
800
700
600
500
400
300
200
100
0
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)

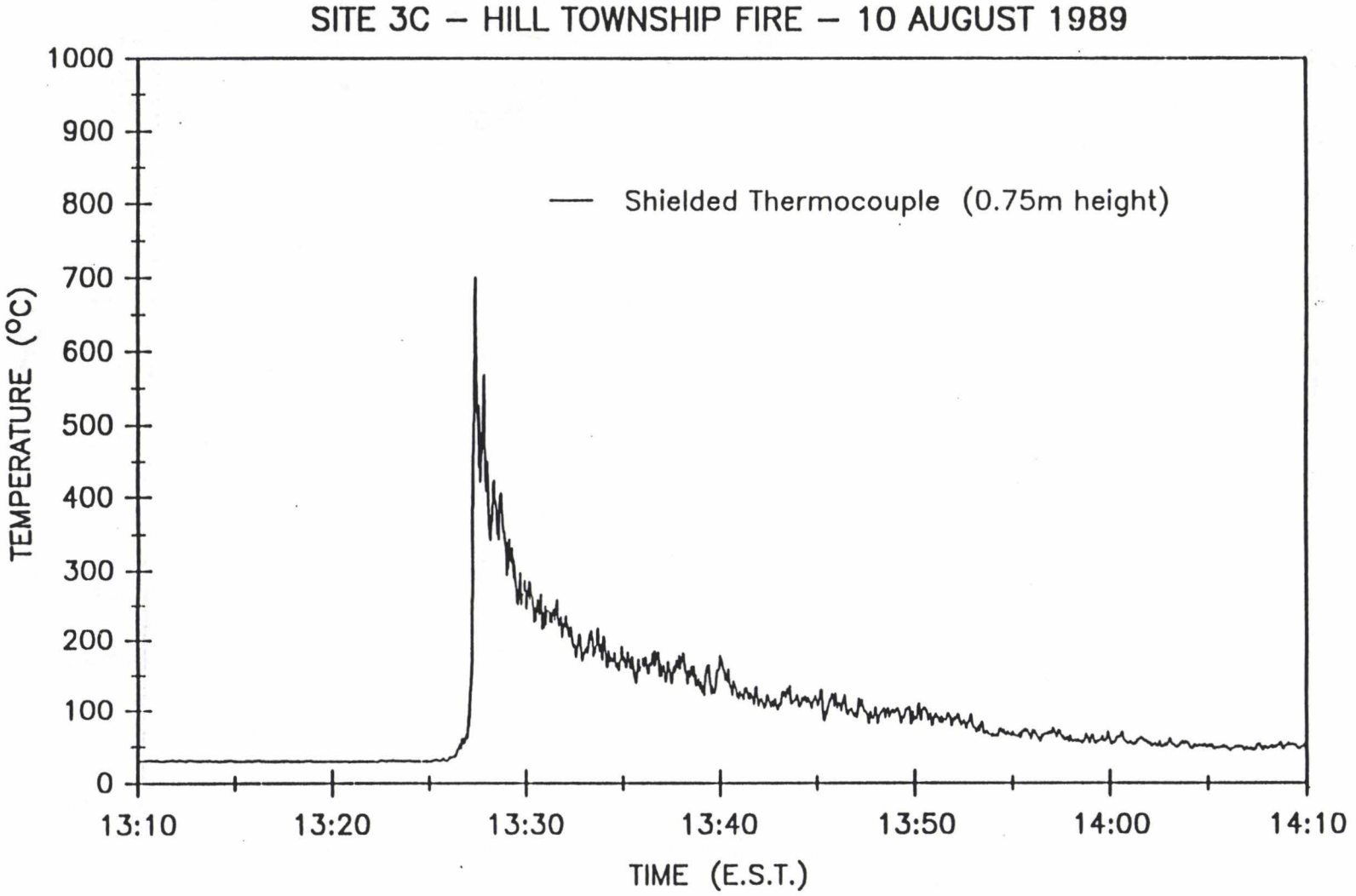

SITE 3B – HILL TOWNSHIP FIRE – 10 AUGUST 1989
Shielded Thermocouple (8m height)
TEMPERATURE (°C)
1000
900
800
700
600
500
400
300
200
100
0
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)

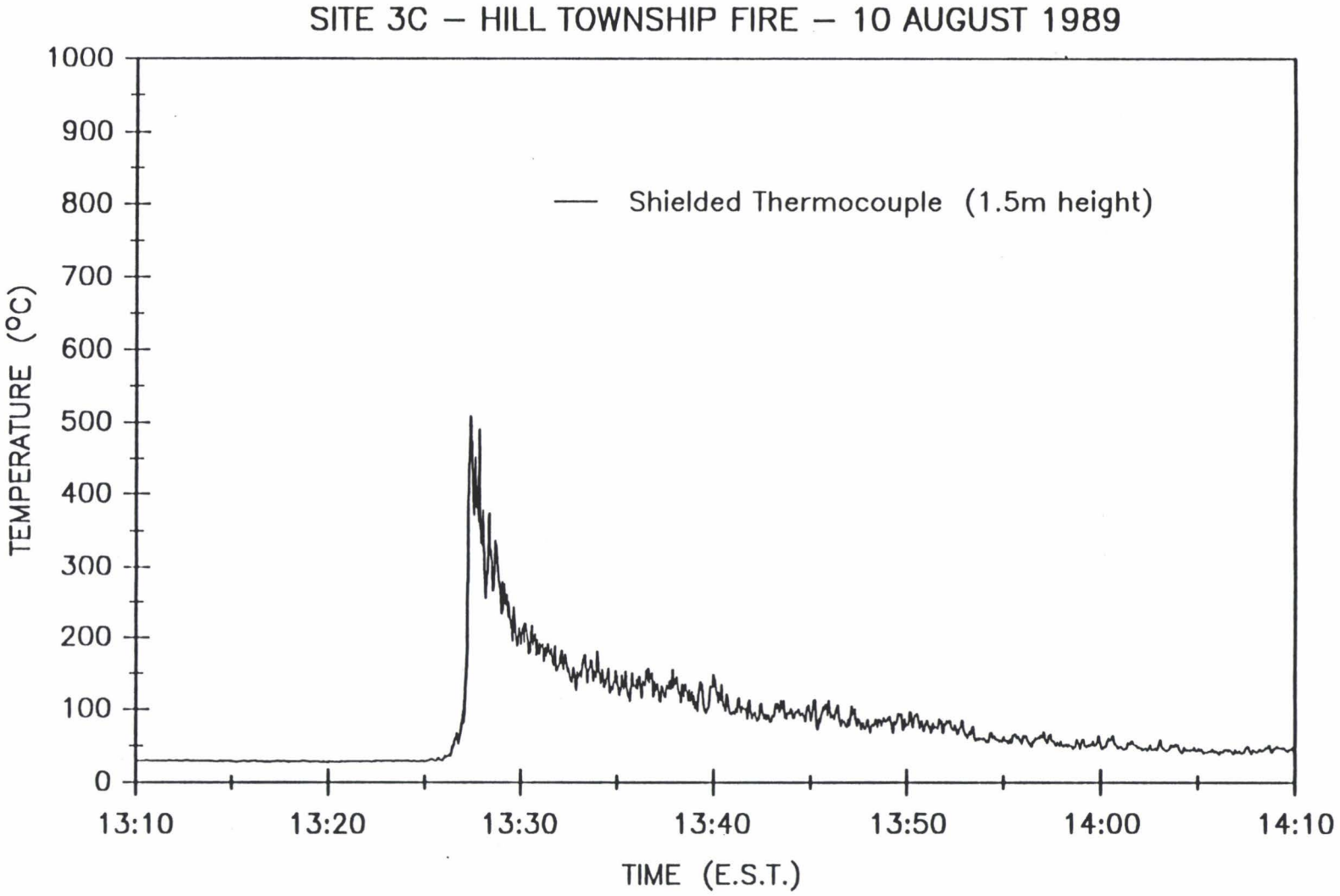
SITE 3 - TOWER C

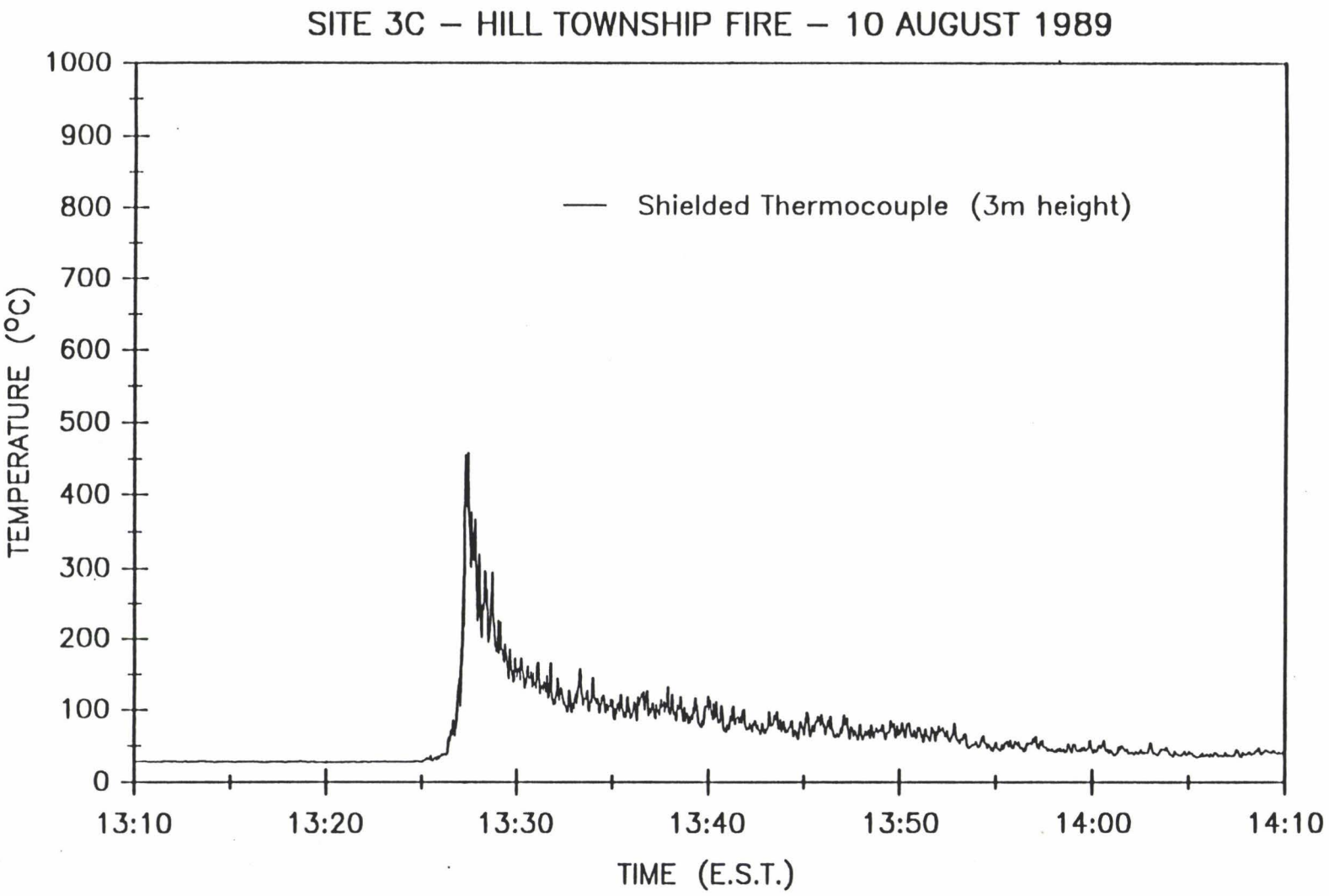

SITE 3C – HILL TOWNSHIP FIRE – 10 AUGUST 1989
Cup Anemometer (8.75m height)
2 second average
WIND SPEED (ms−1)
0
2
4
6
8
10
12
14
16
18
20
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)

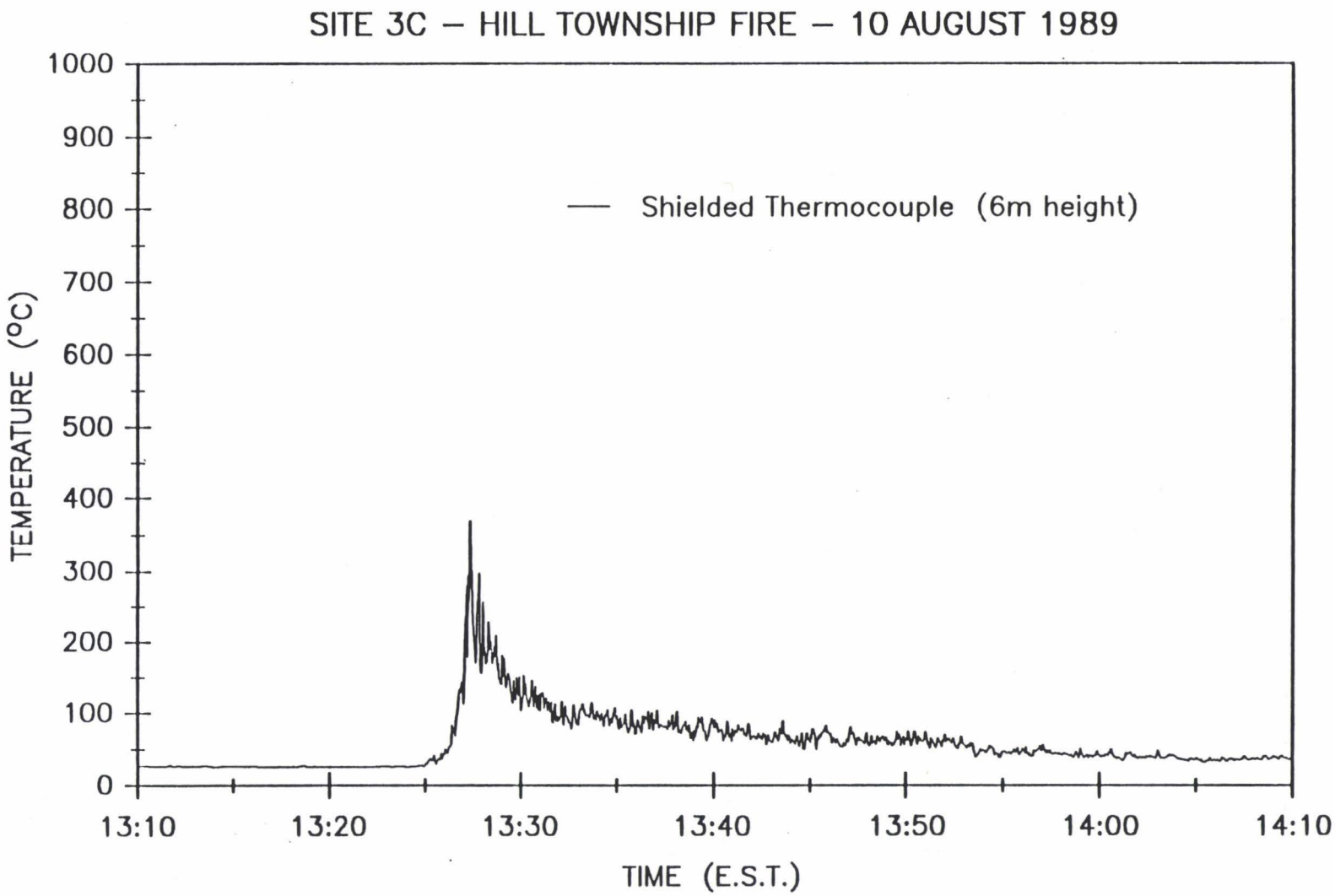

SITE 3C – HILL TOWNSHIP FIRE – 10 AUGUST 1989
360
315
270
225
180
135
90
45
0
WIND DIRECTION (°)
WIND VANE (8.75m height)
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)

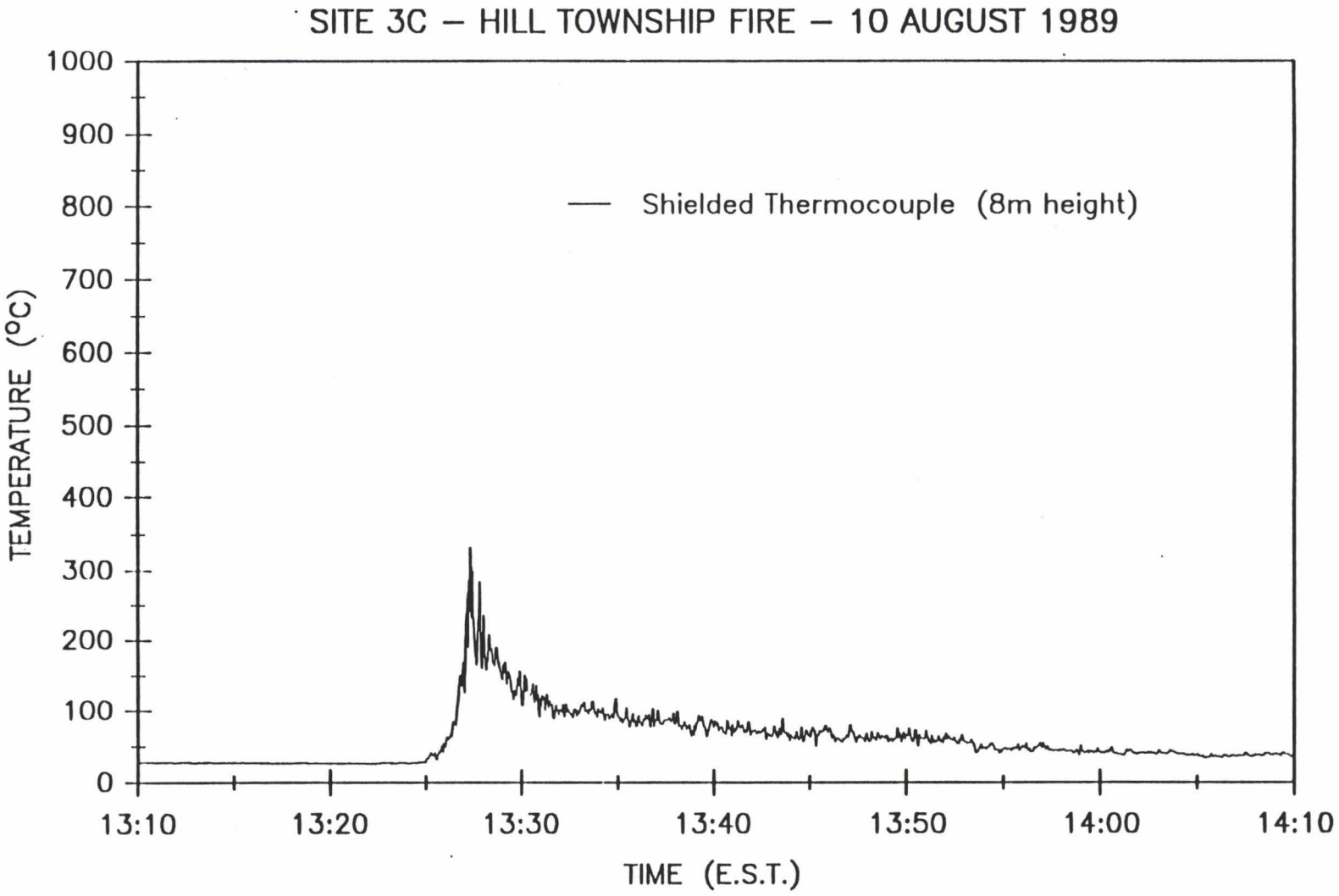

SITE 3C – HILL TOWNSHIP FIRE – 10 AUGUST 1989
Unshielded Thermocouple (surface)
TEMPERATURE (°C)
1000
900
800
700
600
500
400
300
200
100
0
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)


SITE 3C – HILL TOWNSHIP FIRE – 10 AUGUST 1989
Shielded Thermocouple (0.75m height)
TEMPERATURE (°C)
1000
900
800
700
600
500
400
300
200
100
0
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)

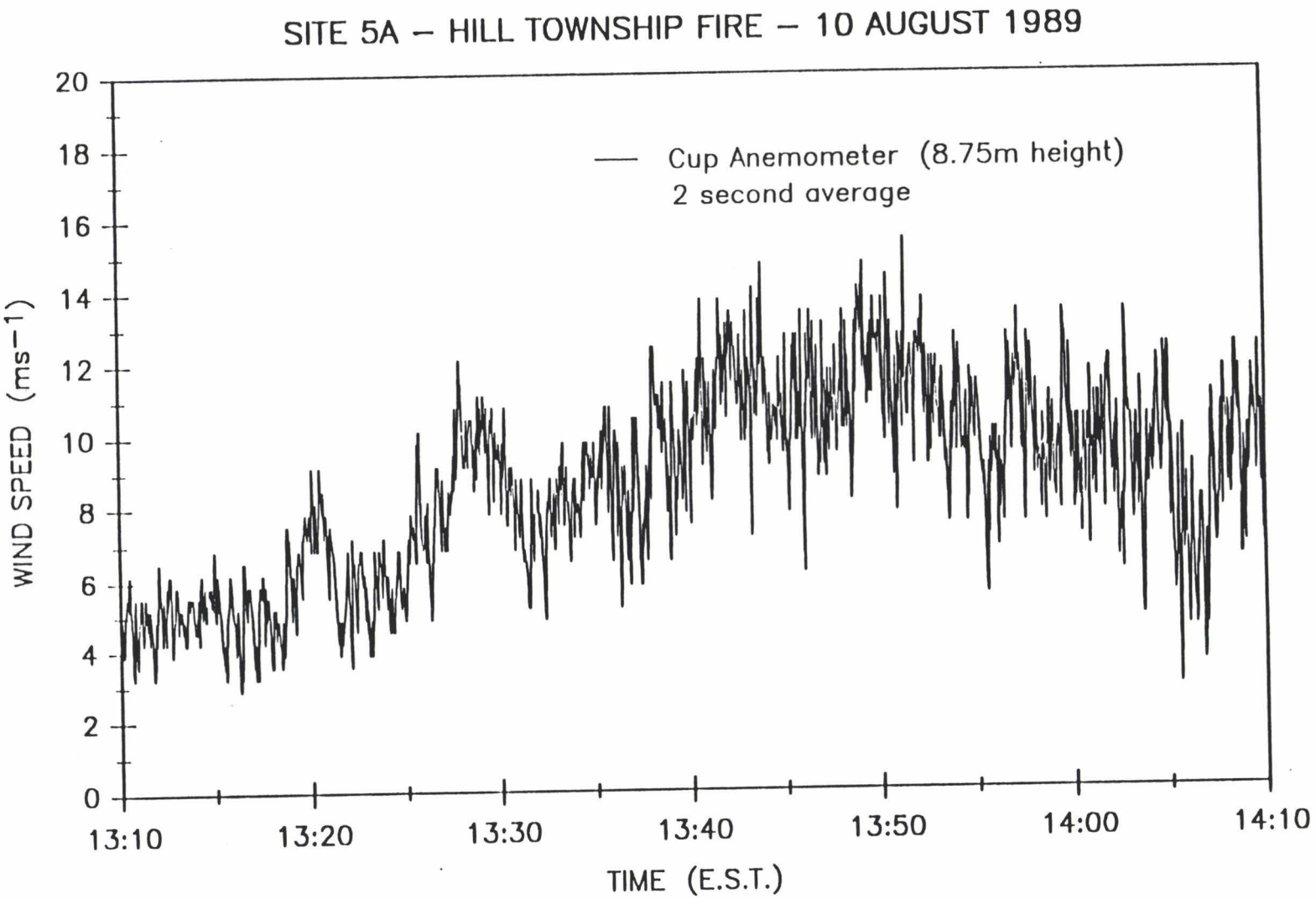

SITE 3C – HILL TOWNSHIP FIRE – 10 AUGUST 1989
Shielded Thermocouple (1.5m height)
TEMPERATURE (°C)
1000
900
800
700
600
500
400
300
200
100
0
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)

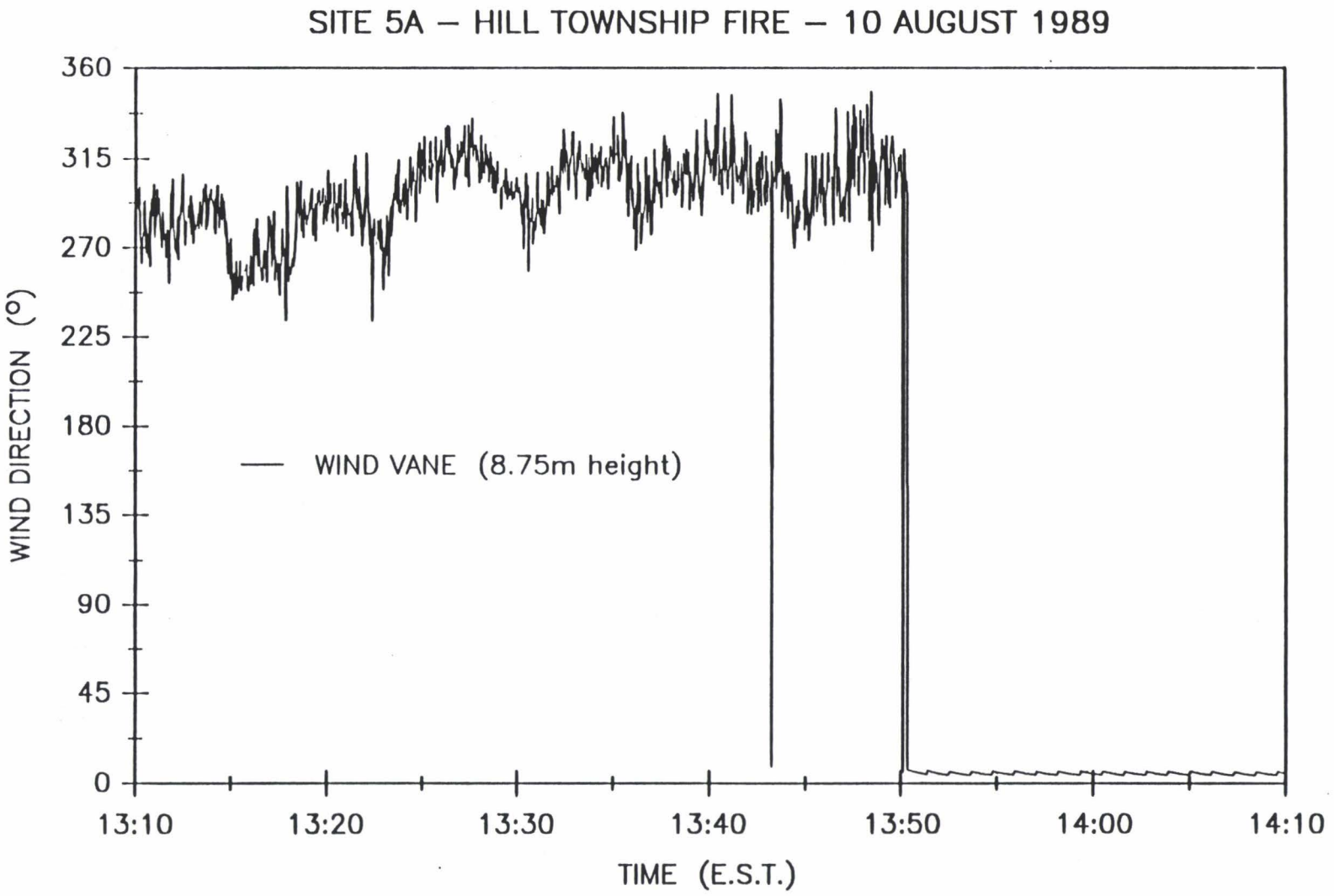

SITE 3C – HILL TOWNSHIP FIRE – 10 AUGUST 1989
Shielded Thermocouple (3m height)
TEMPERATURE (°C)
1000
900
800
700
600
500
400
300
200
100
0
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)

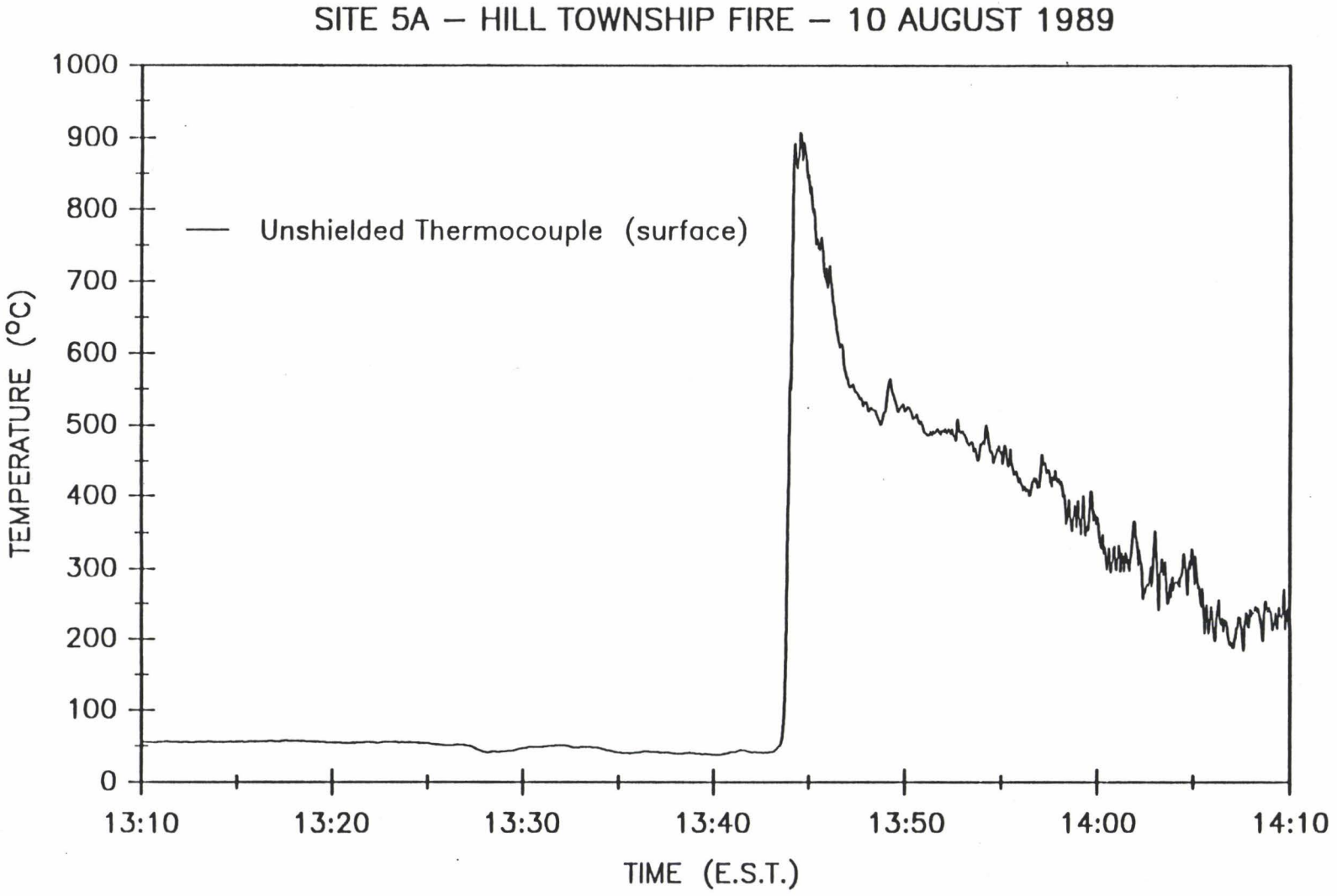

SITE 3C – HILL TOWNSHIP FIRE – 10 AUGUST 1989
Shielded Thermocouple (6m height)
TEMPERATURE (°C)
1000
900
800
700
600
500
400
300
200
100
0
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)

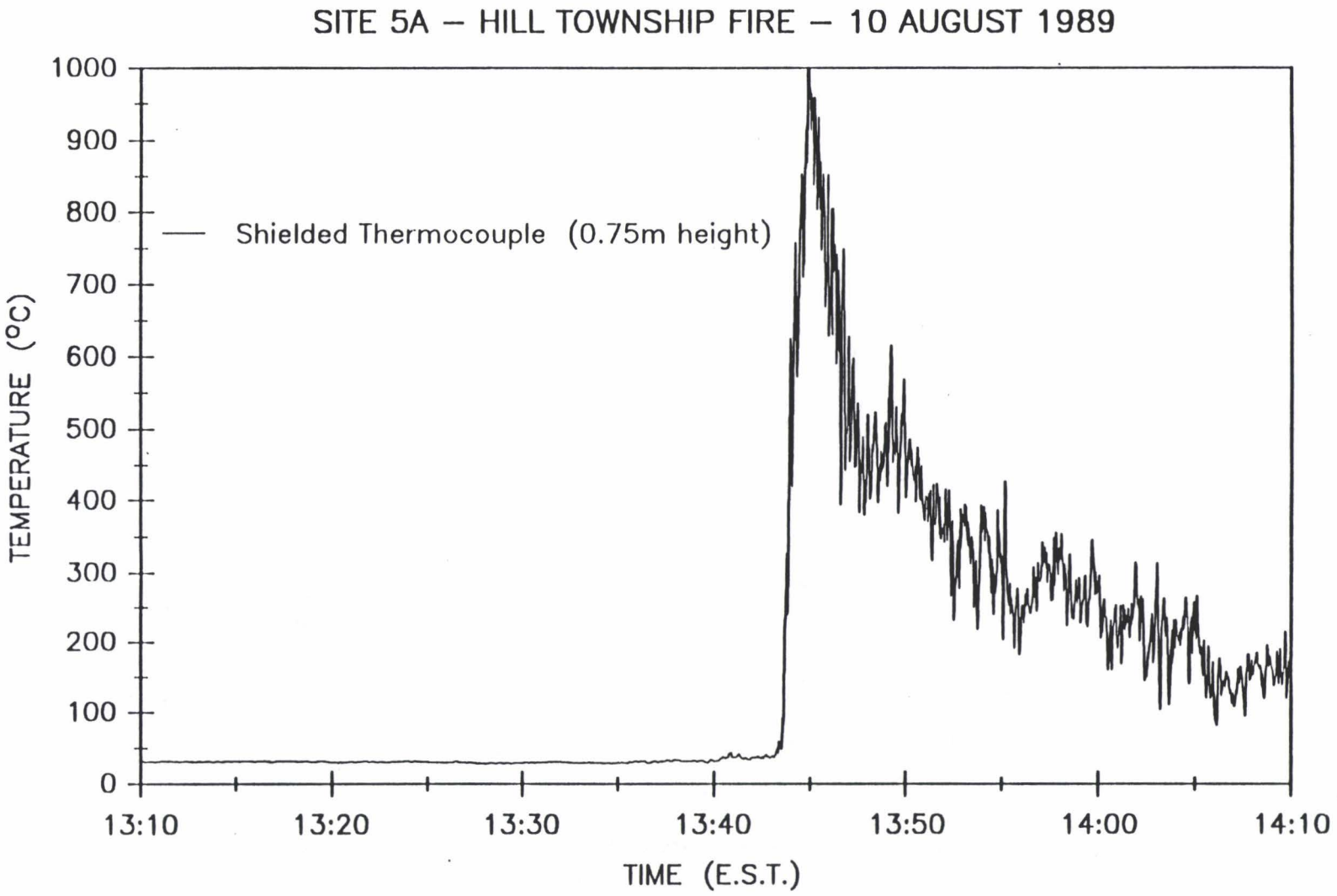

SITE 3C – HILL TOWNSHIP FIRE – 10 AUGUST 1989
Shielded Thermocouple (8m height)
TEMPERATURE (°C)
1000
900
800
700
600
500
400
300
200
100
0
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)

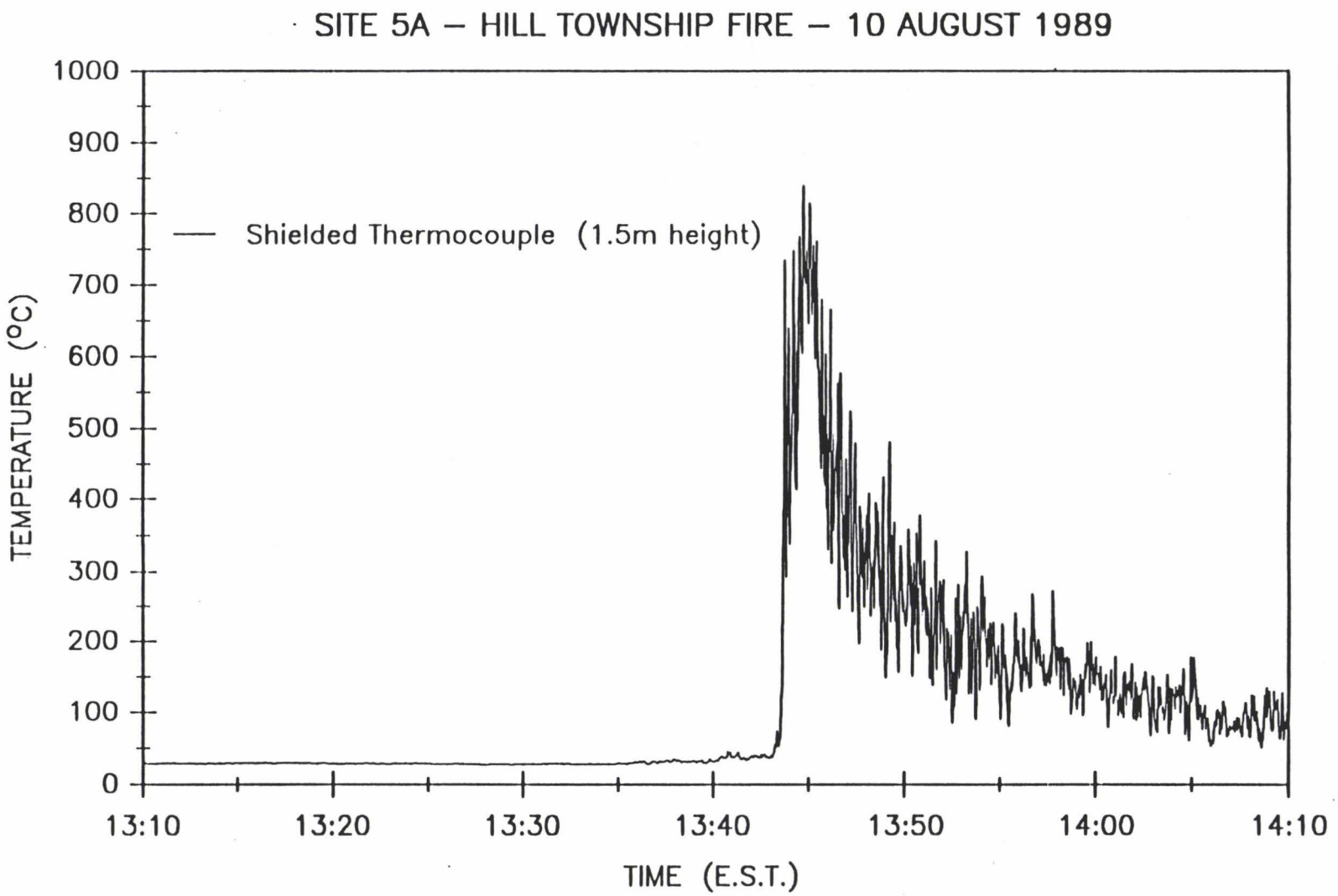
SITE 5 - TOWER A

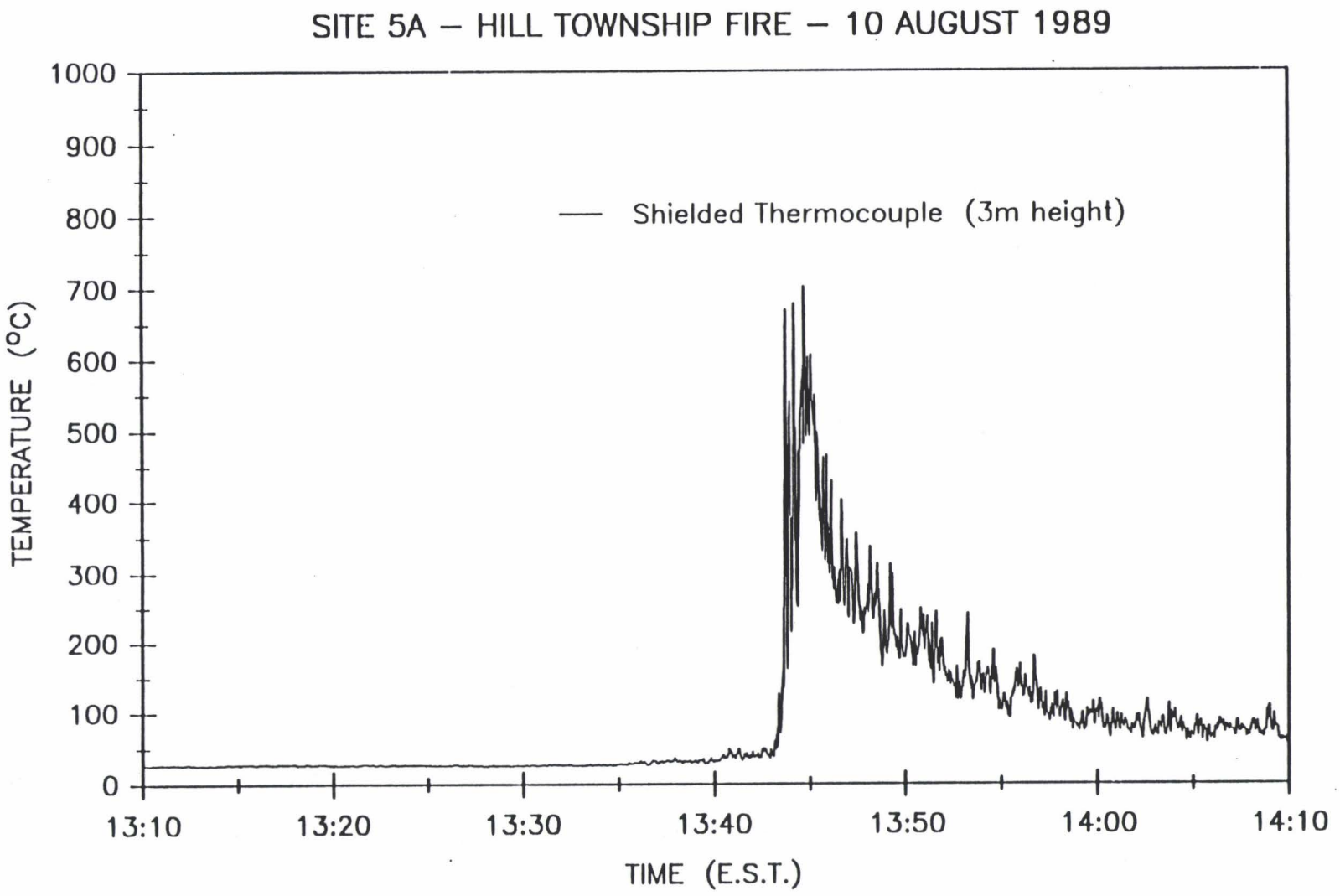

SITE 5A – HILL TOWNSHIP FIRE – 10 AUGUST 1989
Cup Anemometer (8.75m height)
2 second average
WIND SPEED (ms⁻¹)
0
2
4
6
8
10
12
14
16
18
20
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)

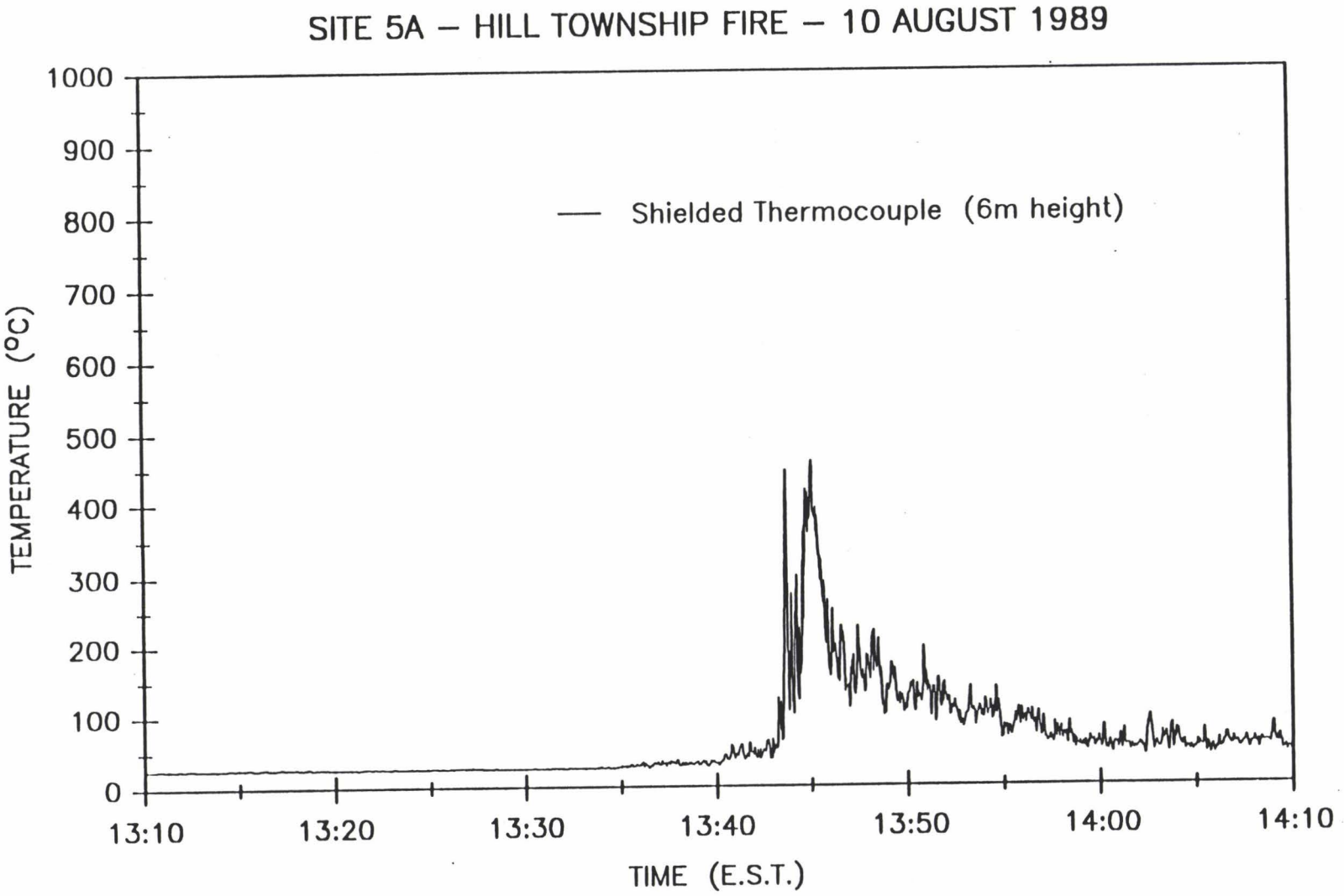

SITE 5A – HILL TOWNSHIP FIRE – 10 AUGUST 1989
WIND DIRECTION (°)
360
315
270
225
180
135
90
45
0
WIND VANE (8.75m height)
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)

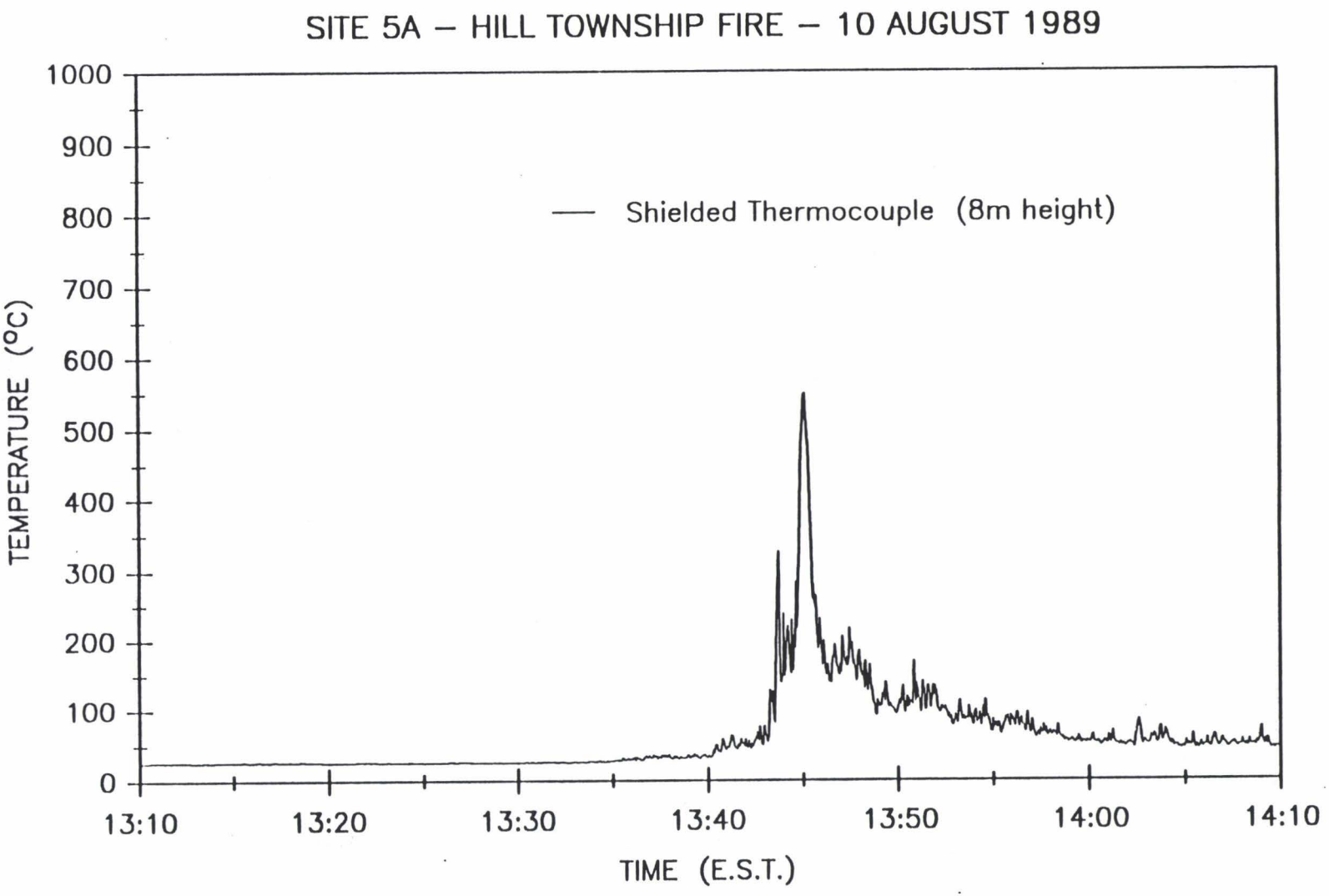

SITE 5A – HILL TOWNSHIP FIRE – 10 AUGUST 1989
Unshielded Thermocouple (surface)
TEMPERATURE (°C)
1000
900
800
700
600
500
400
300
200
100
0
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)


SITE 5A – HILL TOWNSHIP FIRE – 10 AUGUST 1989
Shielded Thermocouple (0.75m height)
TEMPERATURE (°C)
1000
900
800
700
600
500
400
300
200
100
0
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)

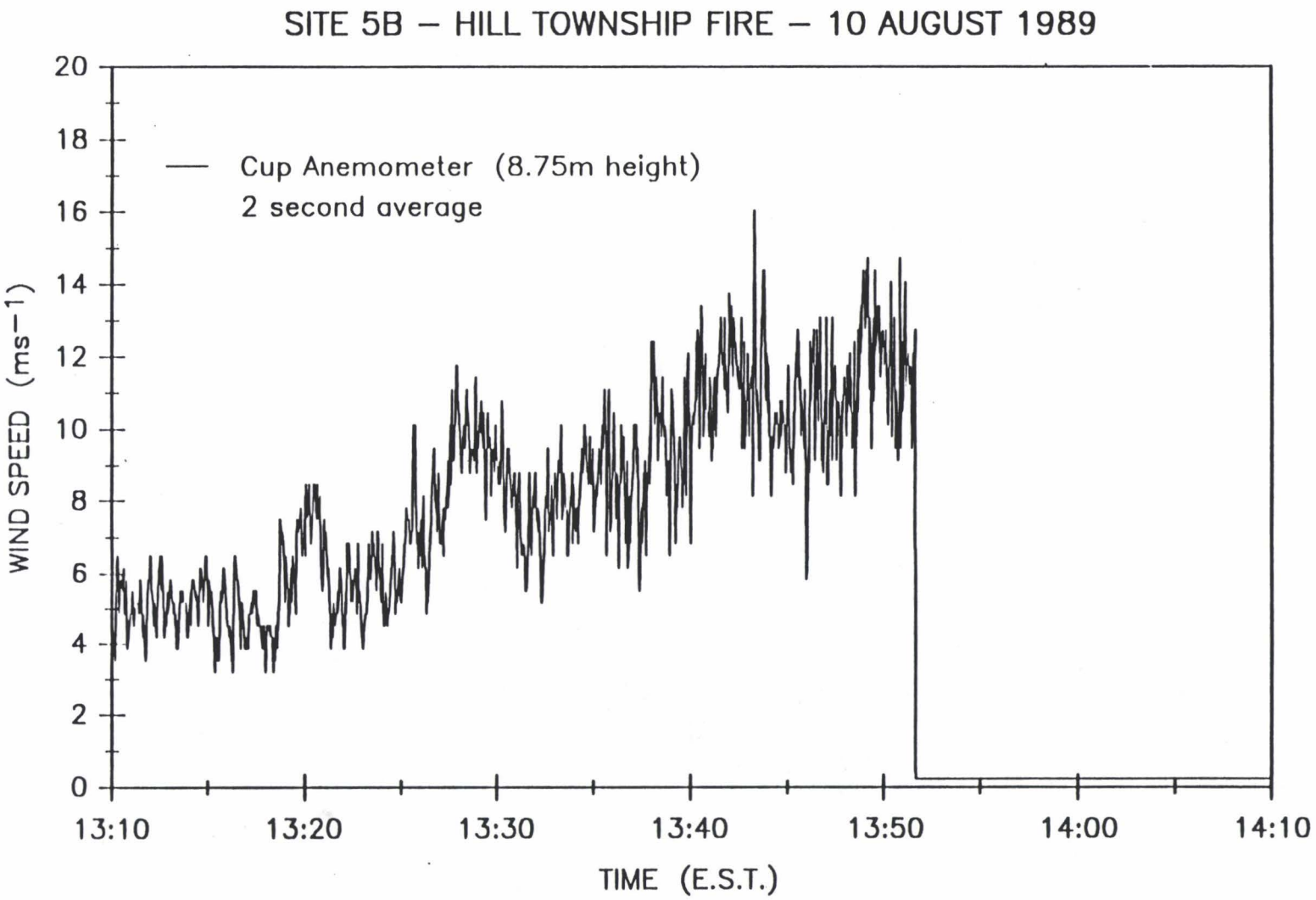

SITE 5A – HILL TOWNSHIP FIRE – 10 AUGUST 1989
Shielded Thermocouple (1.5m height)
TEMPERATURE (°C)
1000
900
800
700
600
500
400
300
200
100
0
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)

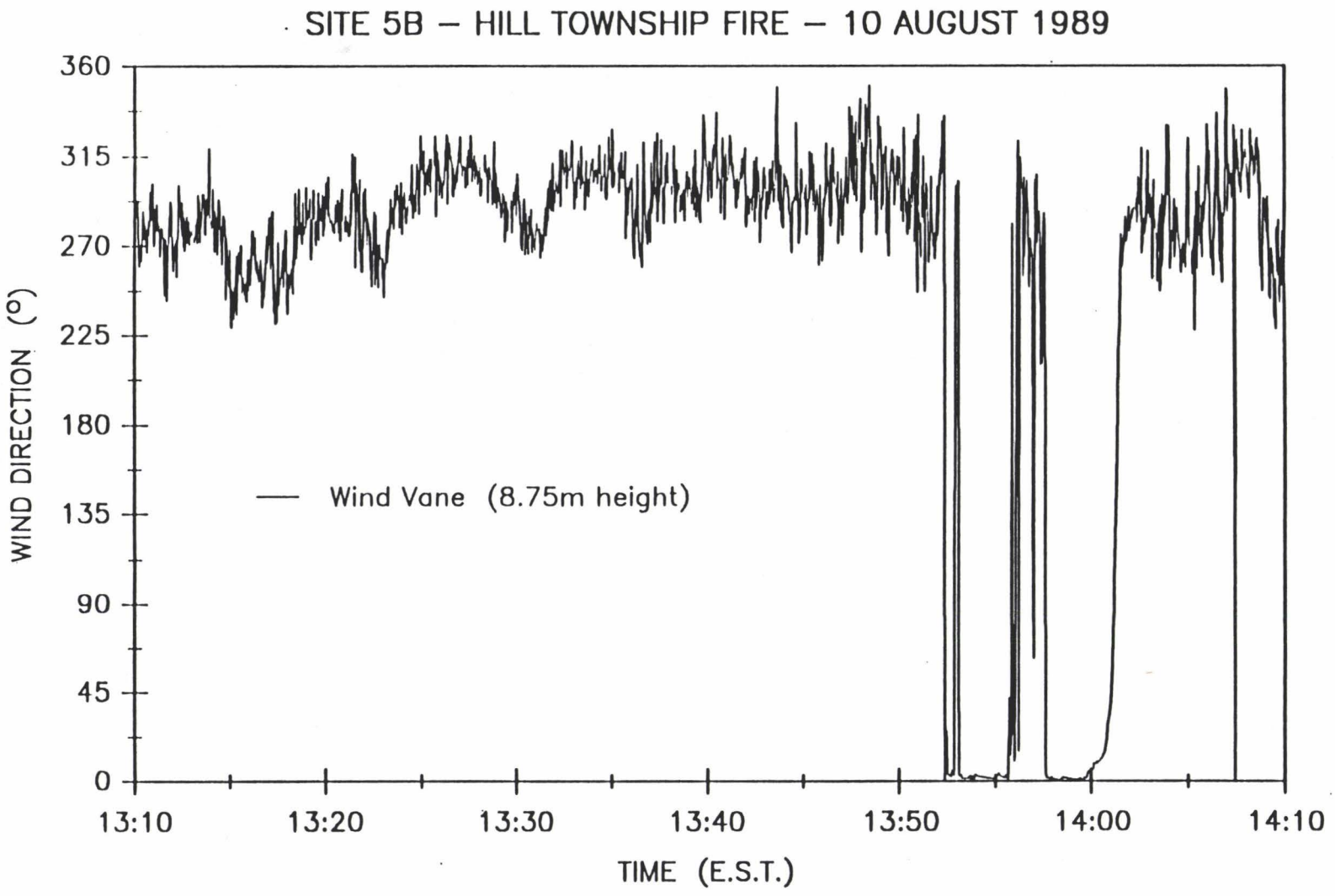

SITE 5A – HILL TOWNSHIP FIRE – 10 AUGUST 1989
Shielded Thermocouple (3m height)
TEMPERATURE (°C)
1000
900
800
700
600
500
400
300
200
100
0
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)

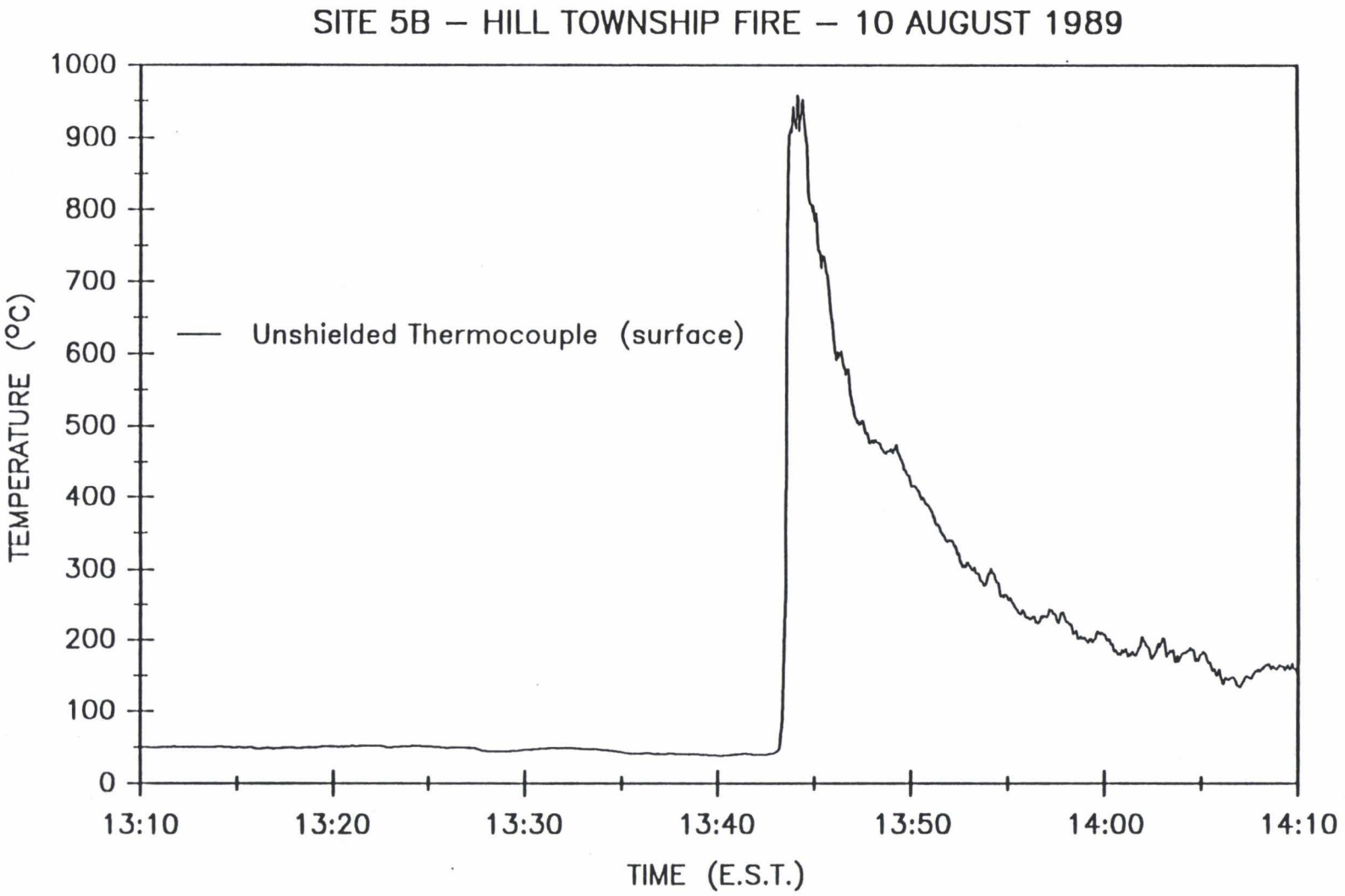

SITE 5A – HILL TOWNSHIP FIRE – 10 AUGUST 1989
Shielded Thermocouple (6m height)
TEMPERATURE (°C)
1000
900
800
700
600
500
400
300
200
100
0
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)

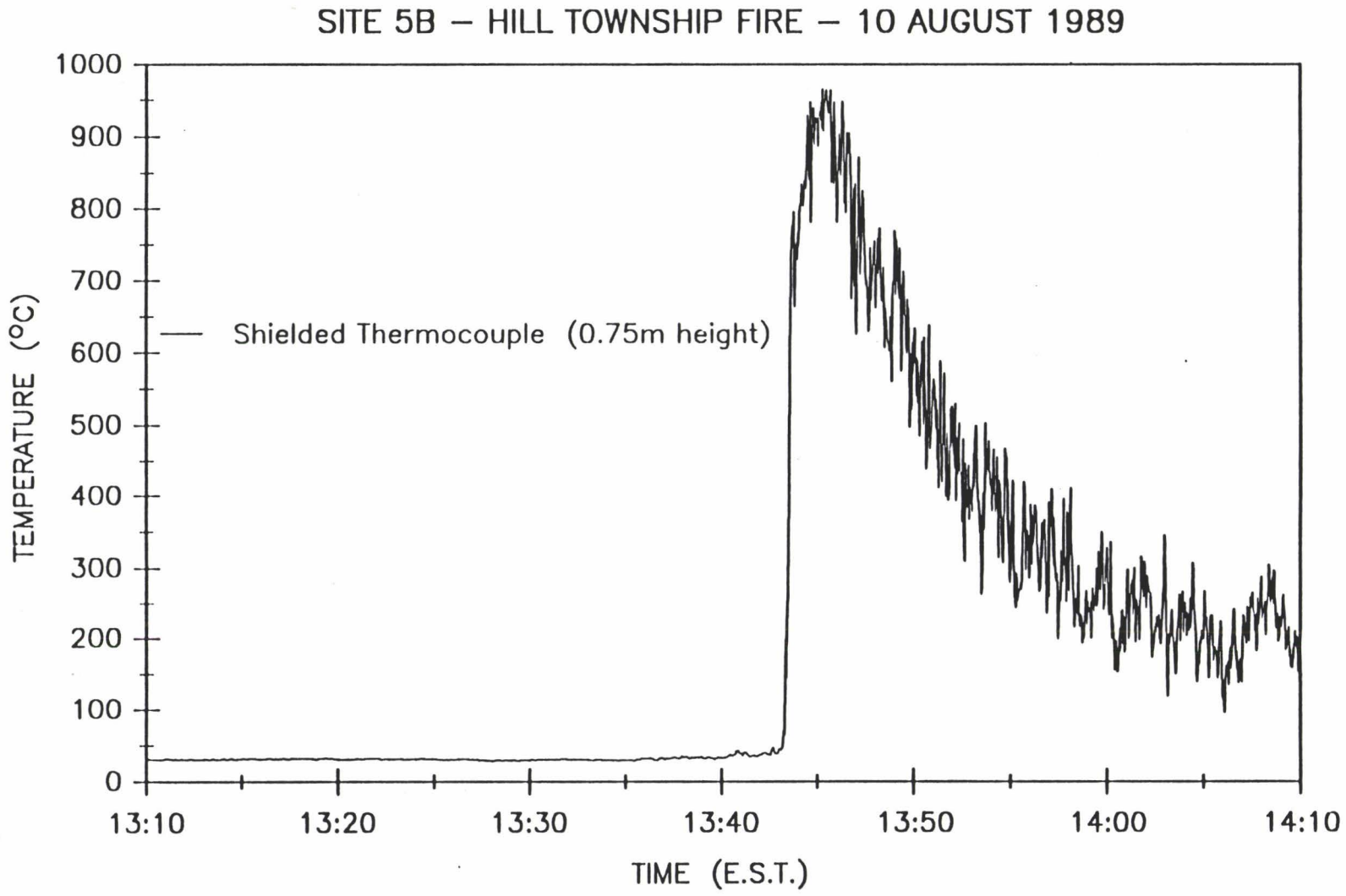

SITE 5A – HILL TOWNSHIP FIRE – 10 AUGUST 1989
Shielded Thermocouple (8m height)
TEMPERATURE (°C)
1000
900
800
700
600
500
400
300
200
100
0
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)

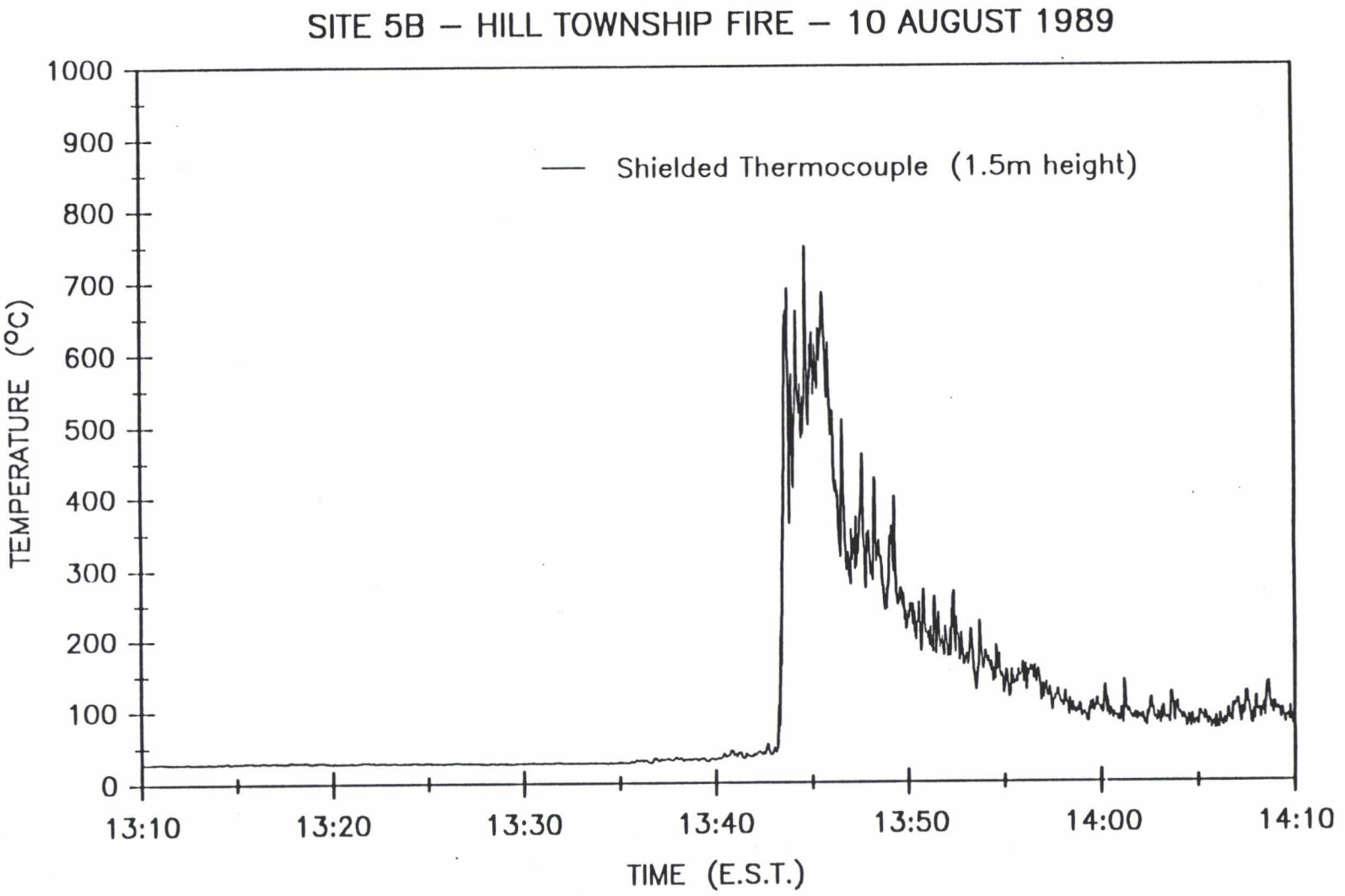
SITE 5 - TOWER B

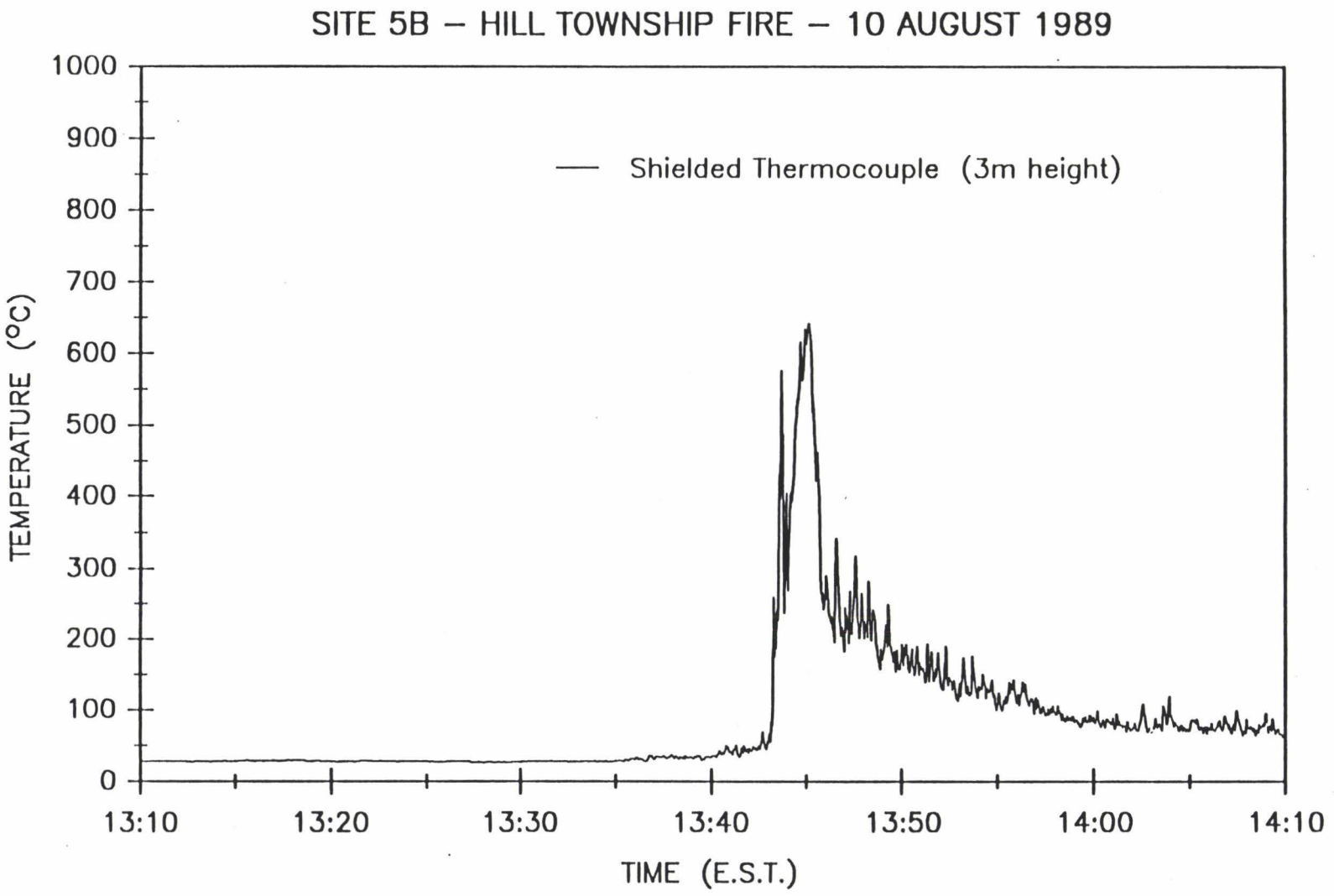

SITE 5B – HILL TOWNSHIP FIRE – 10 AUGUST 1989
Cup Anemometer (8.75m height)
2 second average
WIND SPEED (ms−1)
20
18
16
14
12
10
8
6
4
2
0
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)

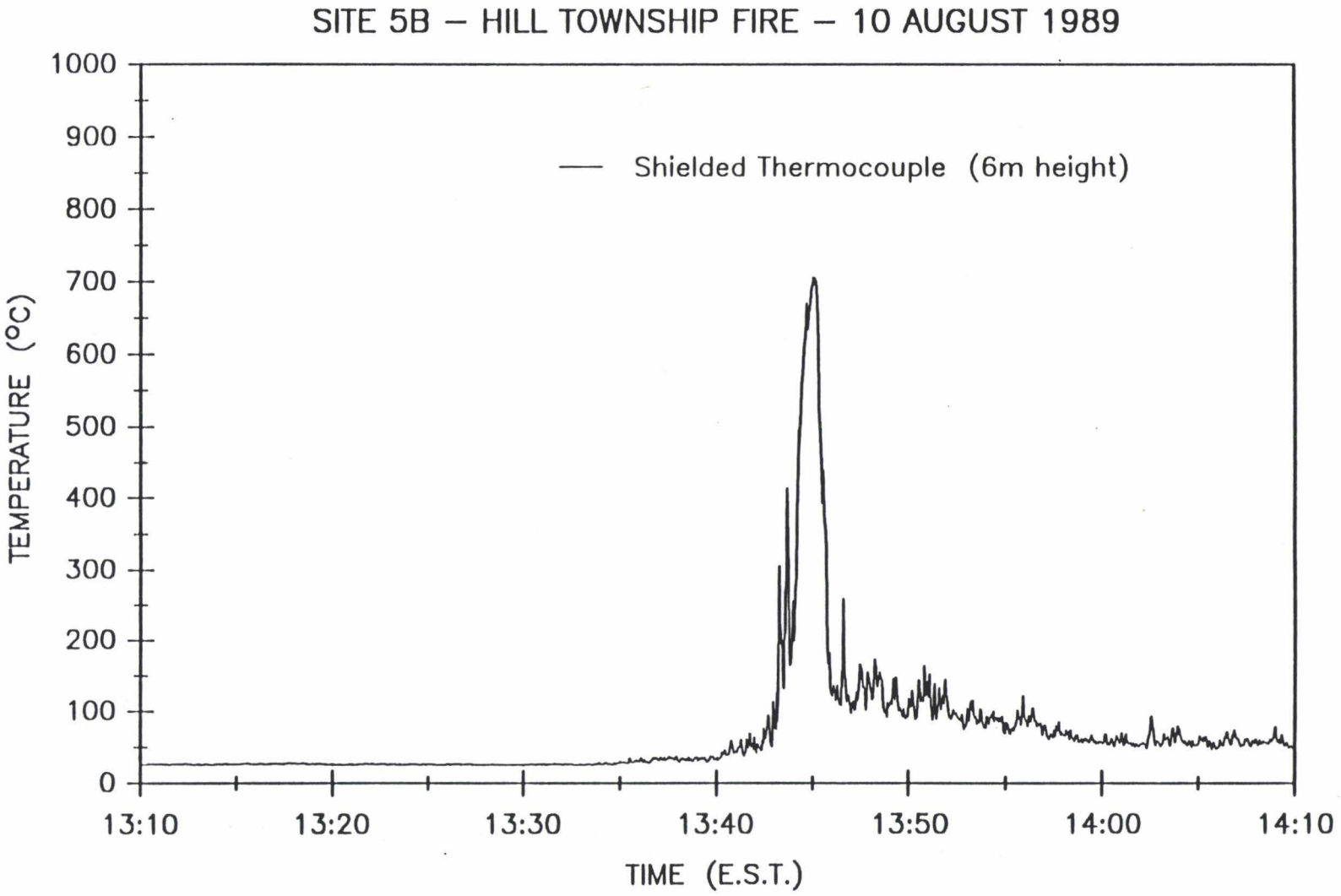

SITE 5B – HILL TOWNSHIP FIRE – 10 AUGUST 1989
360
315
270
225
180
135
90
45
0
WIND DIRECTION (°)
Wind Vane (8.75m height)
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)

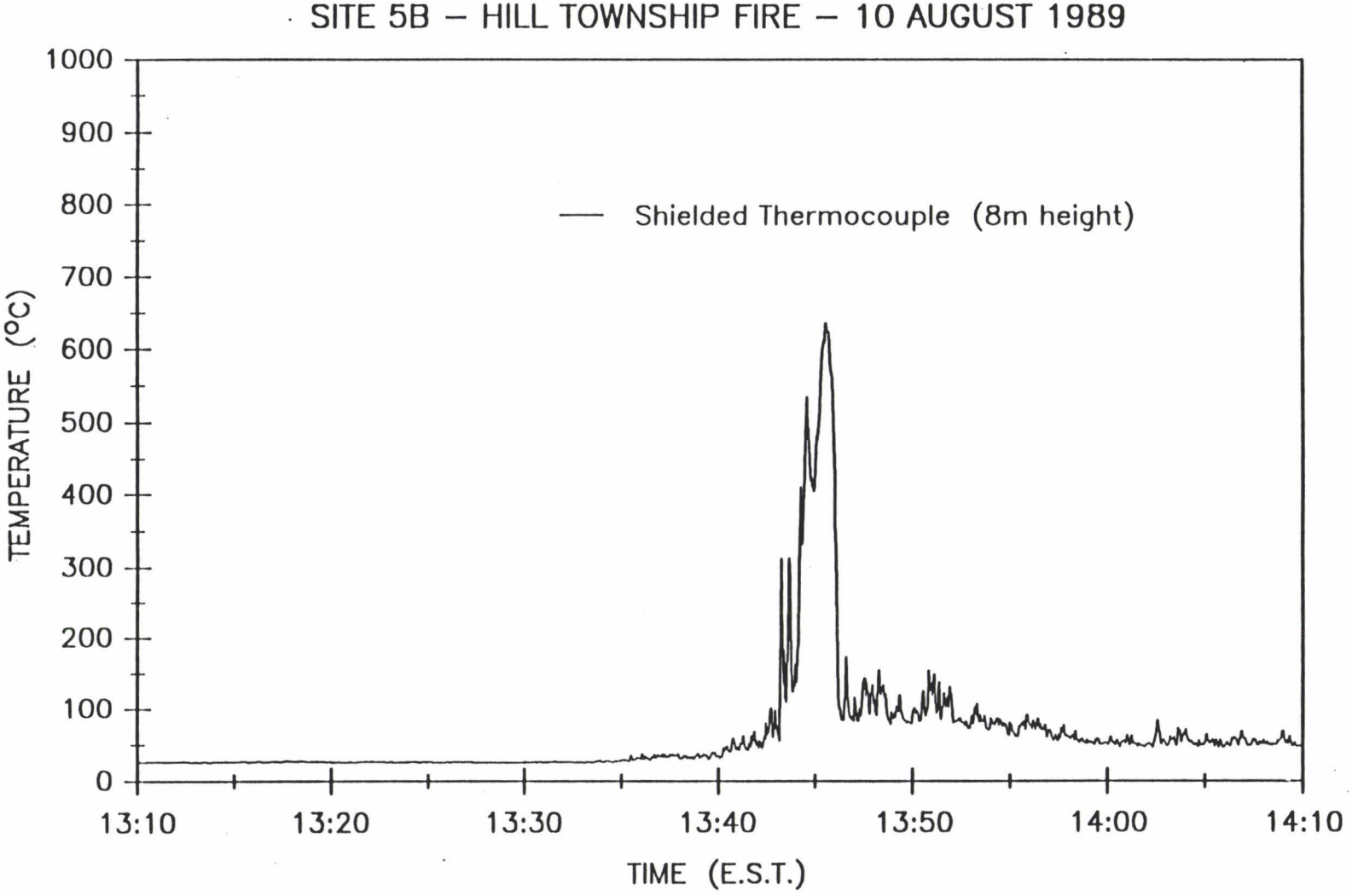

SITE 5B – HILL TOWNSHIP FIRE – 10 AUGUST 1989
TEMPERATURE (°C)
1000
900
800
700
600
500
400
300
200
100
0
Unshielded Thermocouple (surface)
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)


SITE 5B – HILL TOWNSHIP FIRE – 10 AUGUST 1989
TEMPERATURE (°C)
1000
900
800
700
600
500
400
300
200
100
0
Shielded Thermocouple (0.75m height)
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)

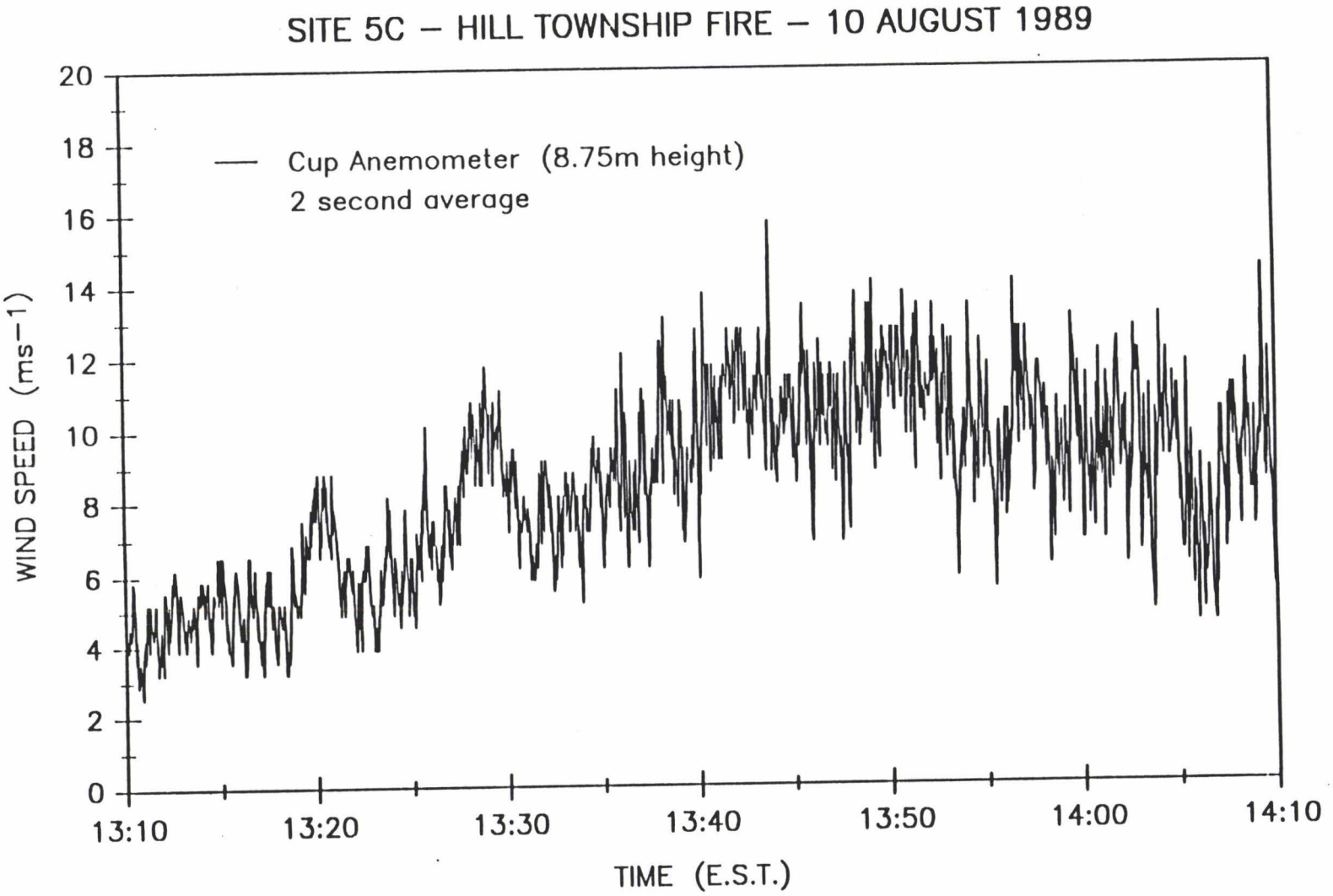

SITE 5B – HILL TOWNSHIP FIRE – 10 AUGUST 1989
Shielded Thermocouple (1.5m height)
TEMPERATURE (°C)
1000
900
800
700
600
500
400
300
200
100
0
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)

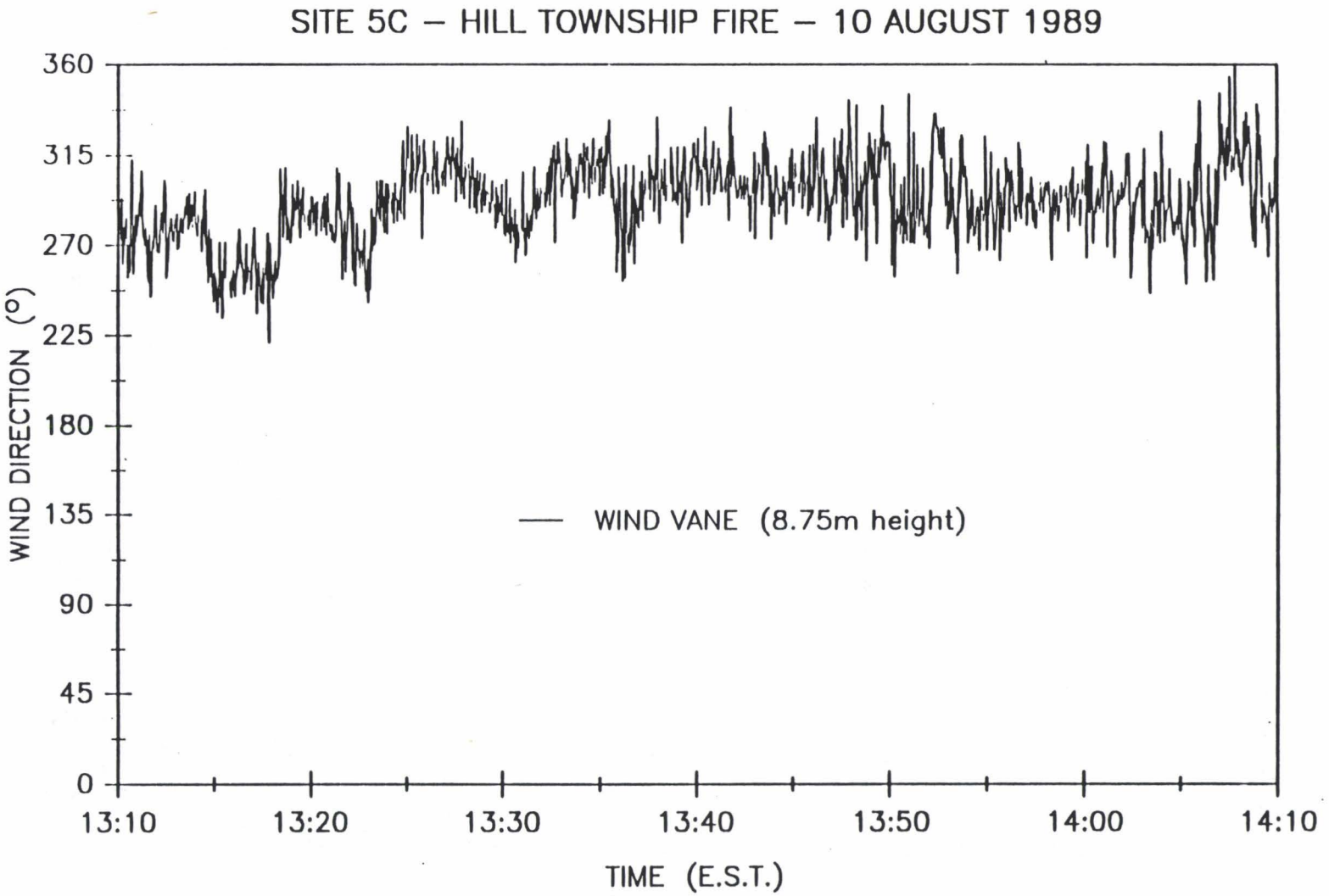

SITE 5B – HILL TOWNSHIP FIRE – 10 AUGUST 1989
Shielded Thermocouple (3m height)
TEMPERATURE (°C)
1000
900
800
700
600
500
400
300
200
100
0
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)

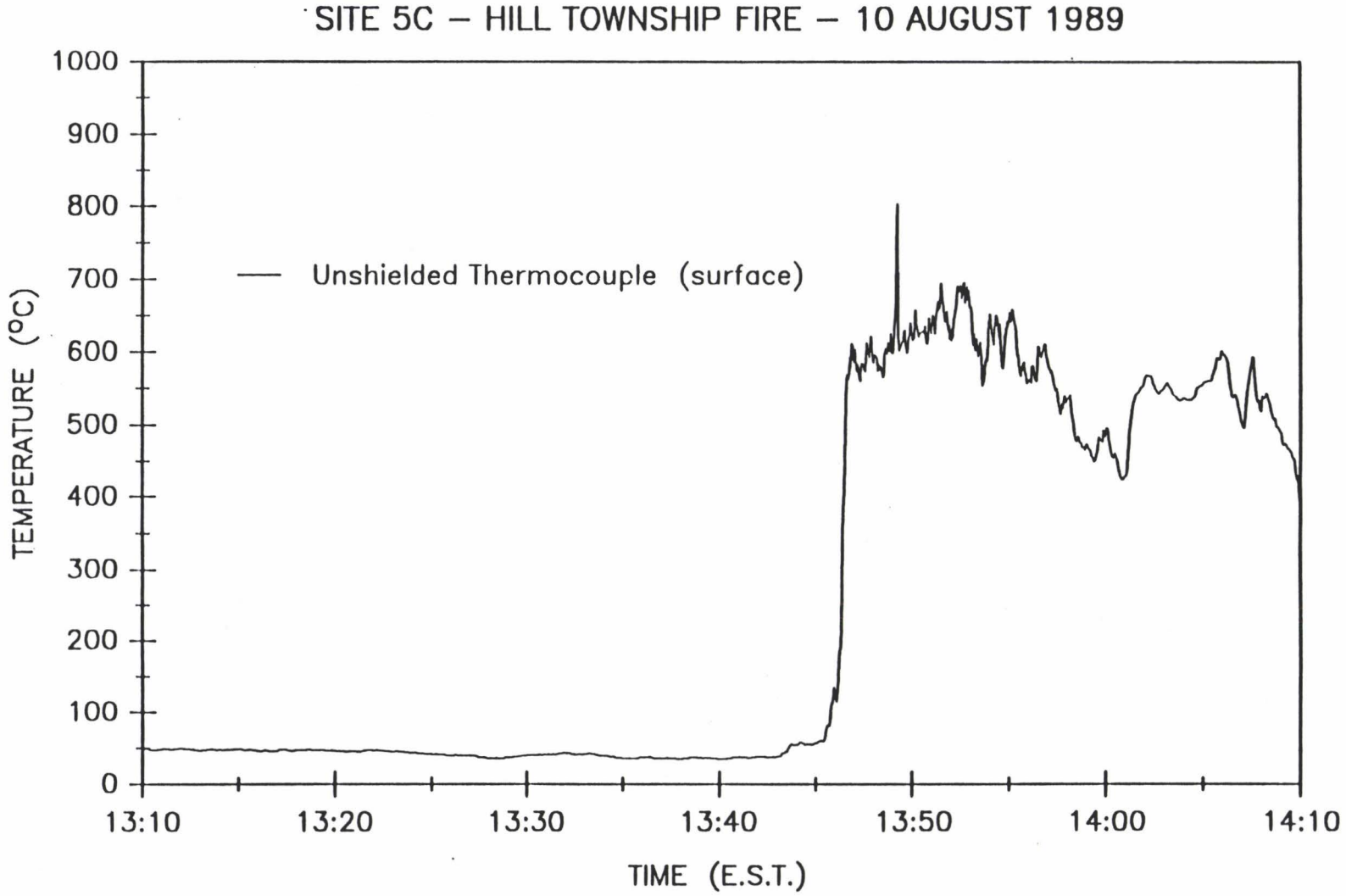

SITE 5B – HILL TOWNSHIP FIRE – 10 AUGUST 1989
Shielded Thermocouple (6m height)
TEMPERATURE (°C)
1000
900
800
700
600
500
400
300
200
100
0
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)

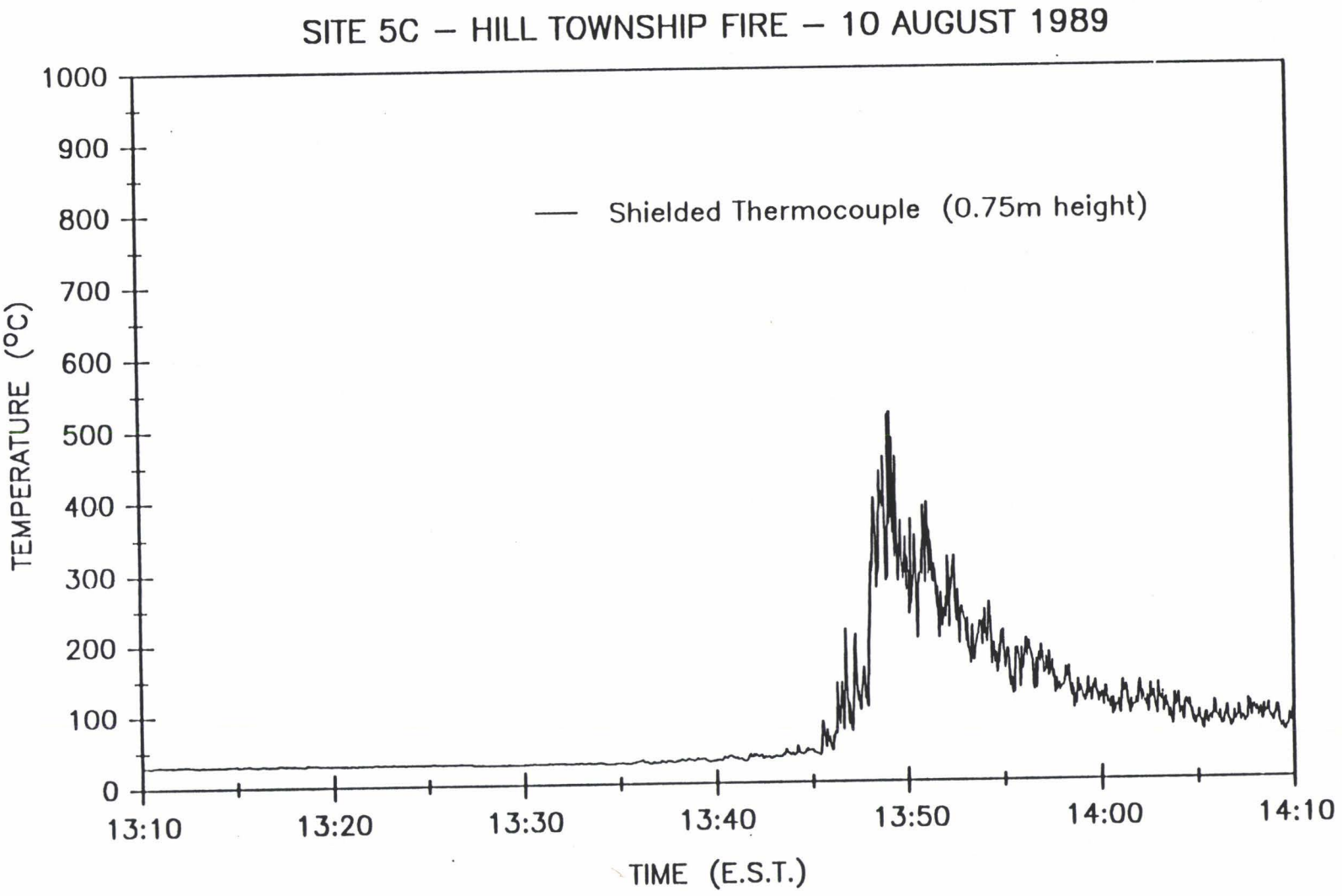

SITE 5B – HILL TOWNSHIP FIRE – 10 AUGUST 1989
Shielded Thermocouple (8m height)
TEMPERATURE (°C)
1000
900
800
700
600
500
400
300
200
100
0
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)

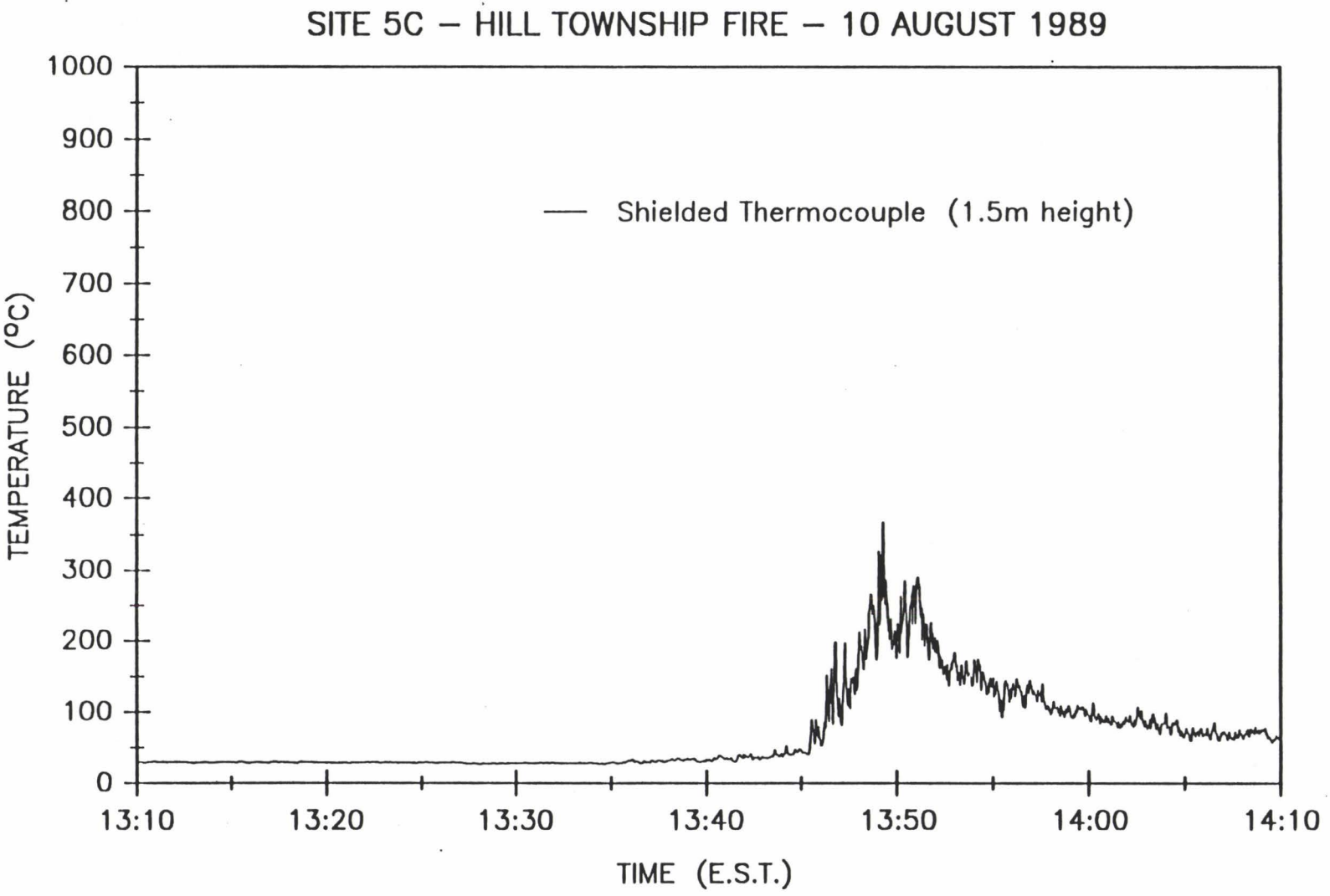
SITE 5 - TOWER C

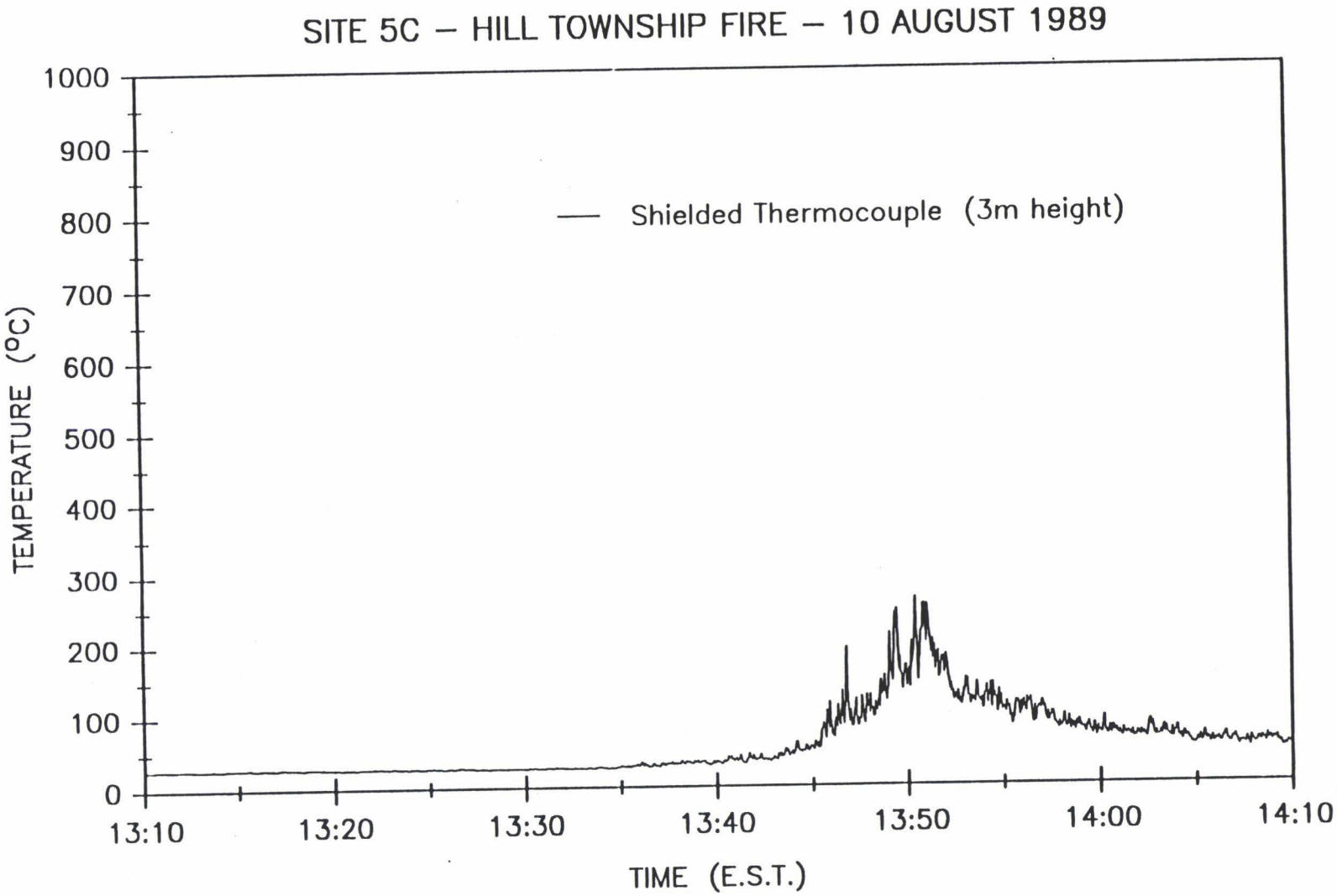

SITE 5C – HILL TOWNSHIP FIRE – 10 AUGUST 1989
Cup Anemometer (8.75m height)
2 second average
WIND SPEED (ms−1)
20
18
16
14
12
10
8
6
4
2
0
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)

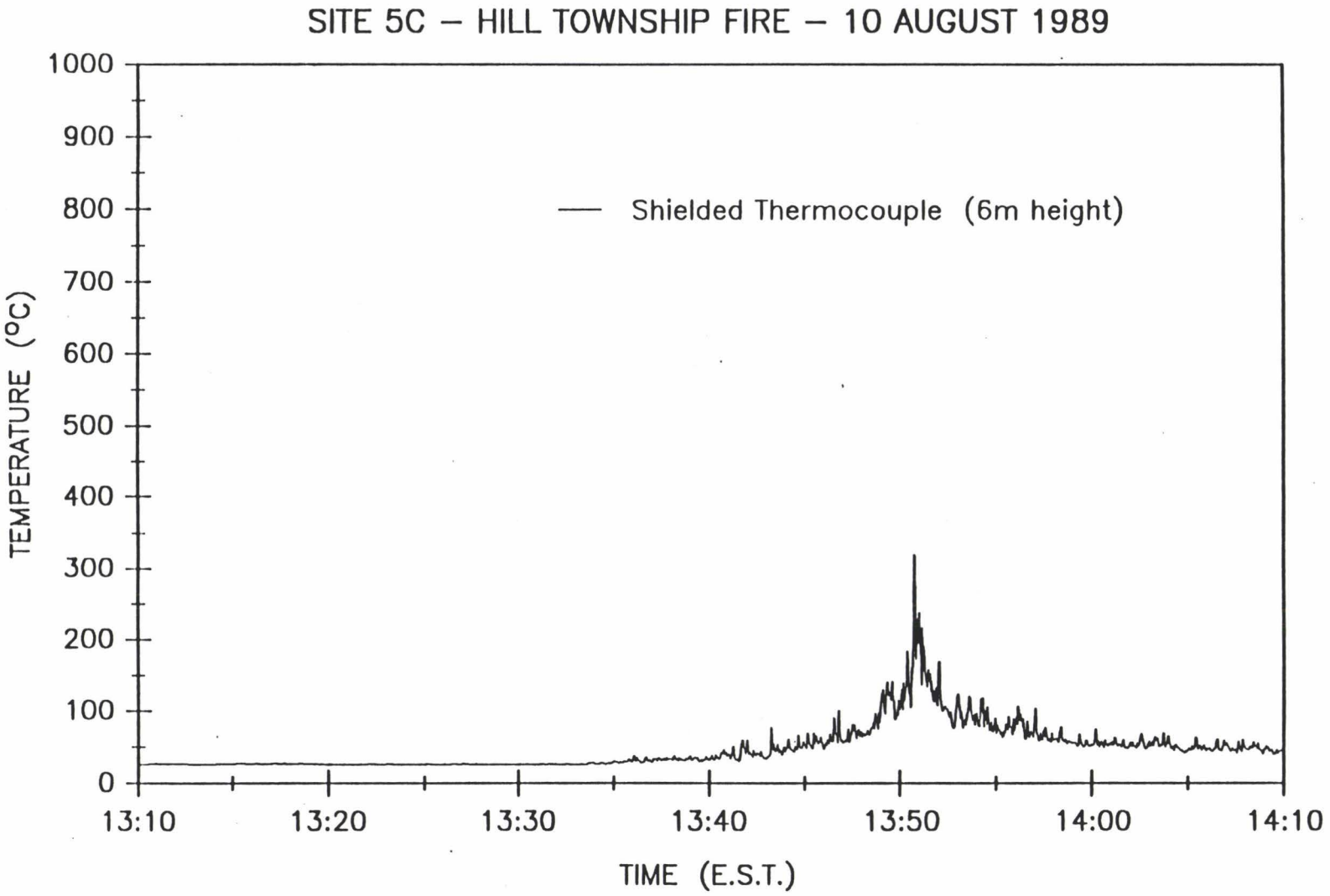

SITE 5C – HILL TOWNSHIP FIRE – 10 AUGUST 1989
360
315
270
225
180
135
90
45
0
WIND DIRECTION (°)
WIND VANE (8.75m height)
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)

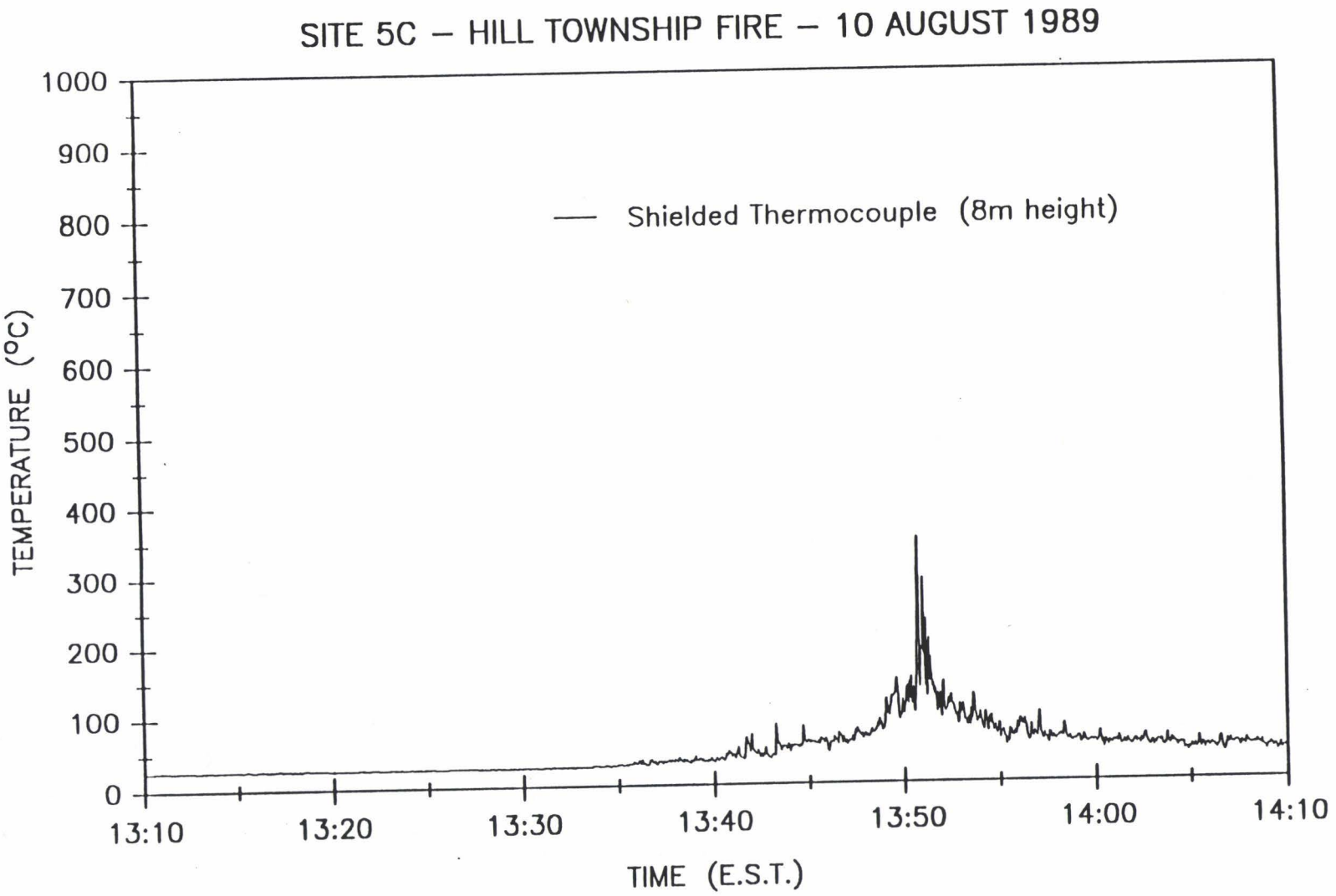

SITE 5C – HILL TOWNSHIP FIRE – 10 AUGUST 1989
Unshielded Thermocouple (surface)
TEMPERATURE (°C)
1000
900
800
700
600
500
400
300
200
100
0
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)


SITE 5C – HILL TOWNSHIP FIRE – 10 AUGUST 1989
Shielded Thermocouple (0.75m height)
TEMPERATURE (°C)
1000
900
800
700
600
500
400
300
200
100
0
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)


SITE 5C – HILL TOWNSHIP FIRE – 10 AUGUST 1989
Shielded Thermocouple (1.5m height)
TEMPERATURE (°C)
1000
900
800
700
600
500
400
300
200
100
0
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)


SITE 5C – HILL TOWNSHIP FIRE – 10 AUGUST 1989
Shielded Thermocouple (3m height)
TEMPERATURE (°C)
1000
900
800
700
600
500
400
300
200
100
0
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)


SITE 5C – HILL TOWNSHIP FIRE – 10 AUGUST 1989
Shielded Thermocouple (6m height)
TEMPERATURE (°C)
1000
900
800
700
600
500
400
300
200
100
0
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)


SITE 5C – HILL TOWNSHIP FIRE – 10 AUGUST 1989
Shielded Thermocouple (8m height)
TEMPERATURE (°C)
1000
900
800
700
600
500
400
300
200
100
0
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)

APPENDIX II

RESULTS OF THE HILL TOWNSHIP PRESCRIBED BURN:

OBJECTIVES E - J

OVERVIEW

The material presented here relates to objectives E - J outlined in the amended research agreement as follows:

E. Characterization of the horizontal in-fire wind field

F. Characterization of the vertical wind field

G. Integration of the in-fire and perimeter wind field

H. Assemble data on the localized fire spread rates

I. Assemble data on the variation of vertical temperatures

J. Evaluation of sensor designs

The results of the above effort were originally presented in the report entitled: "Progress report on cooperative agreement INT -89419 - RJVA" previously submitted by this P.I. The following materials incorporate the information contained in that report. They provide a general view of the deployment and utilization of additional equipment, a more detailed evaluation of the performance of the instrumentation, sensor arrays and deployment strategies and the integration of the data obtained.

CONTENTS

Characterization of the horizontal in-fire wind field.....111

Characterization of the vertical wind field.....137

Characterization of the in-fire and perimeter wind field.....142

Assessment of the local fire spread rates.....158

Variation in the vertical temperatures profiles.....196

Evaluation of sensor designs.....295

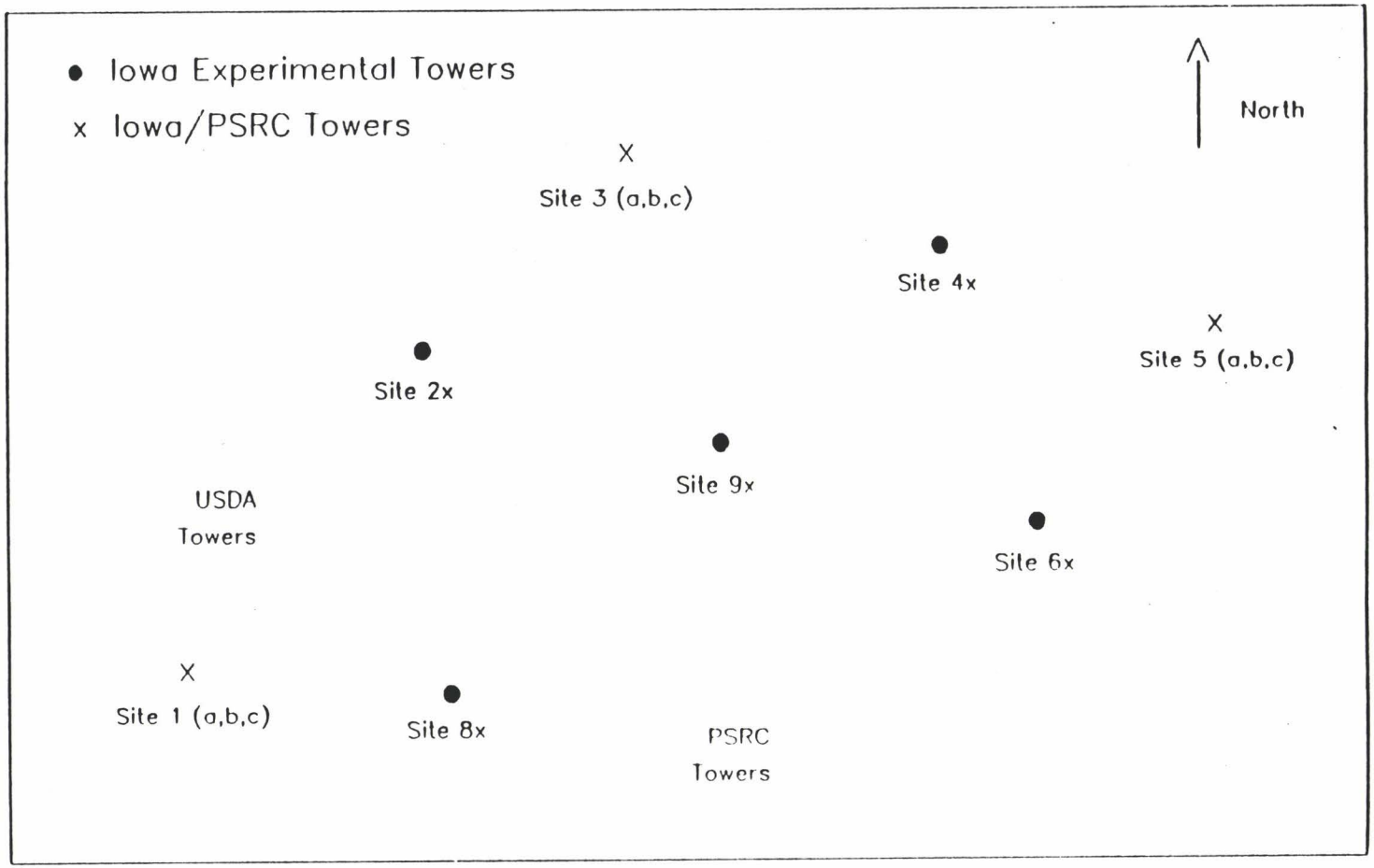
GOAL 1 (OBJECTIVE E)

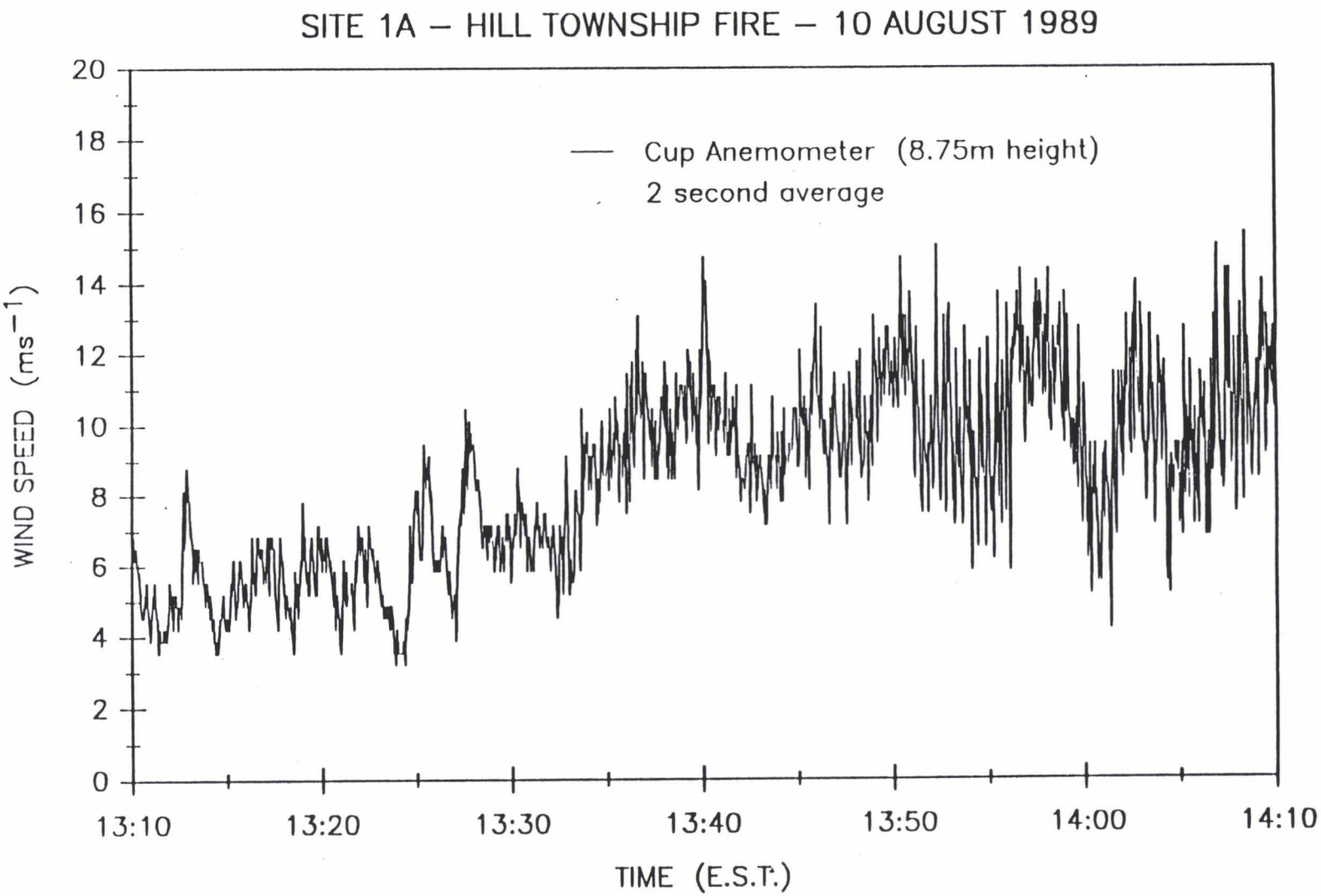
TO CHARACTERIZE THE OVERALL (WHOLE FIRE) NEAR SURFACE (10M) HORIZONTAL WIND FIELD OF THE FIRE UTILIZING CUP ANEMOMETERS AND DIRECTION SENSORS

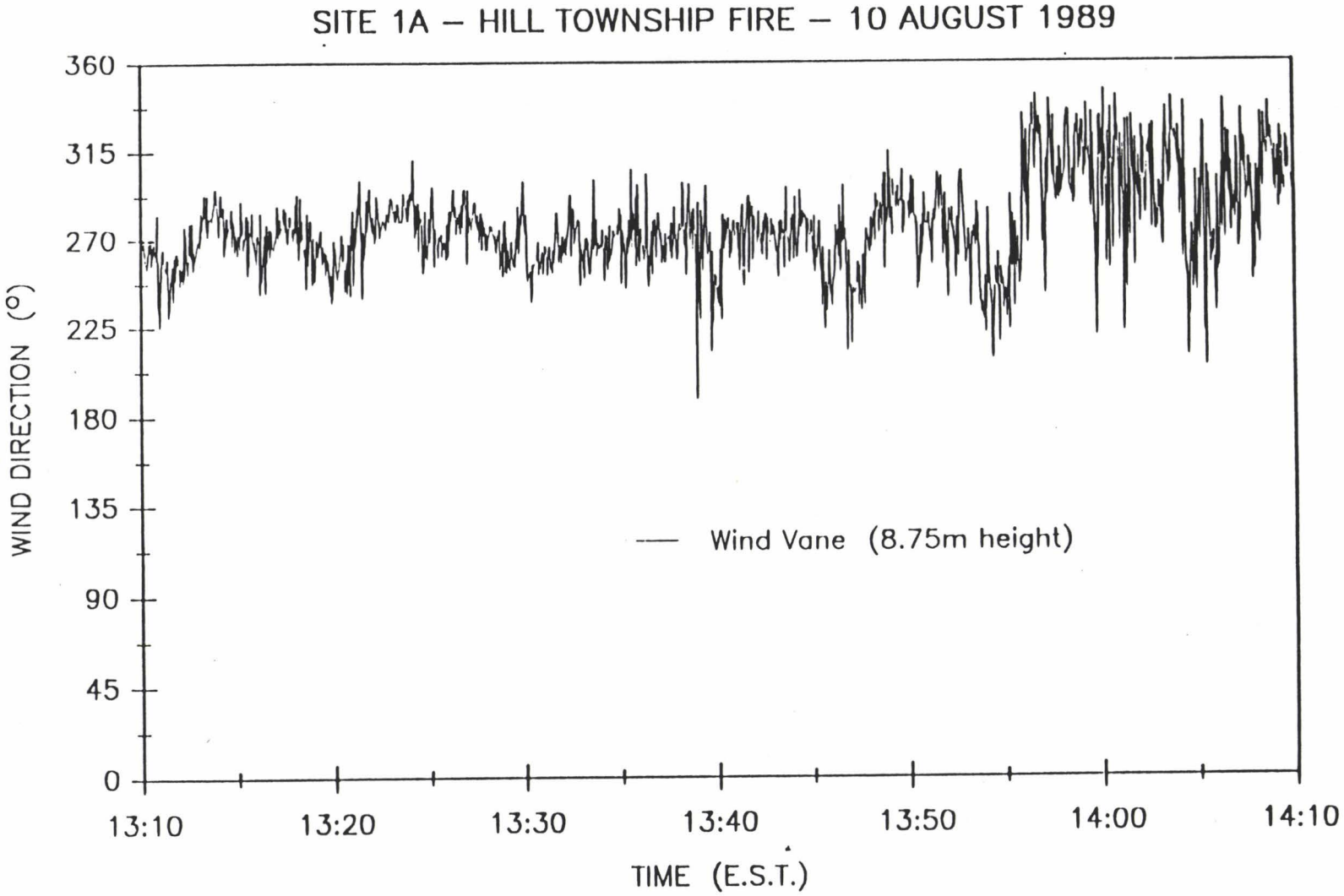
PROGRESS TO DATE:

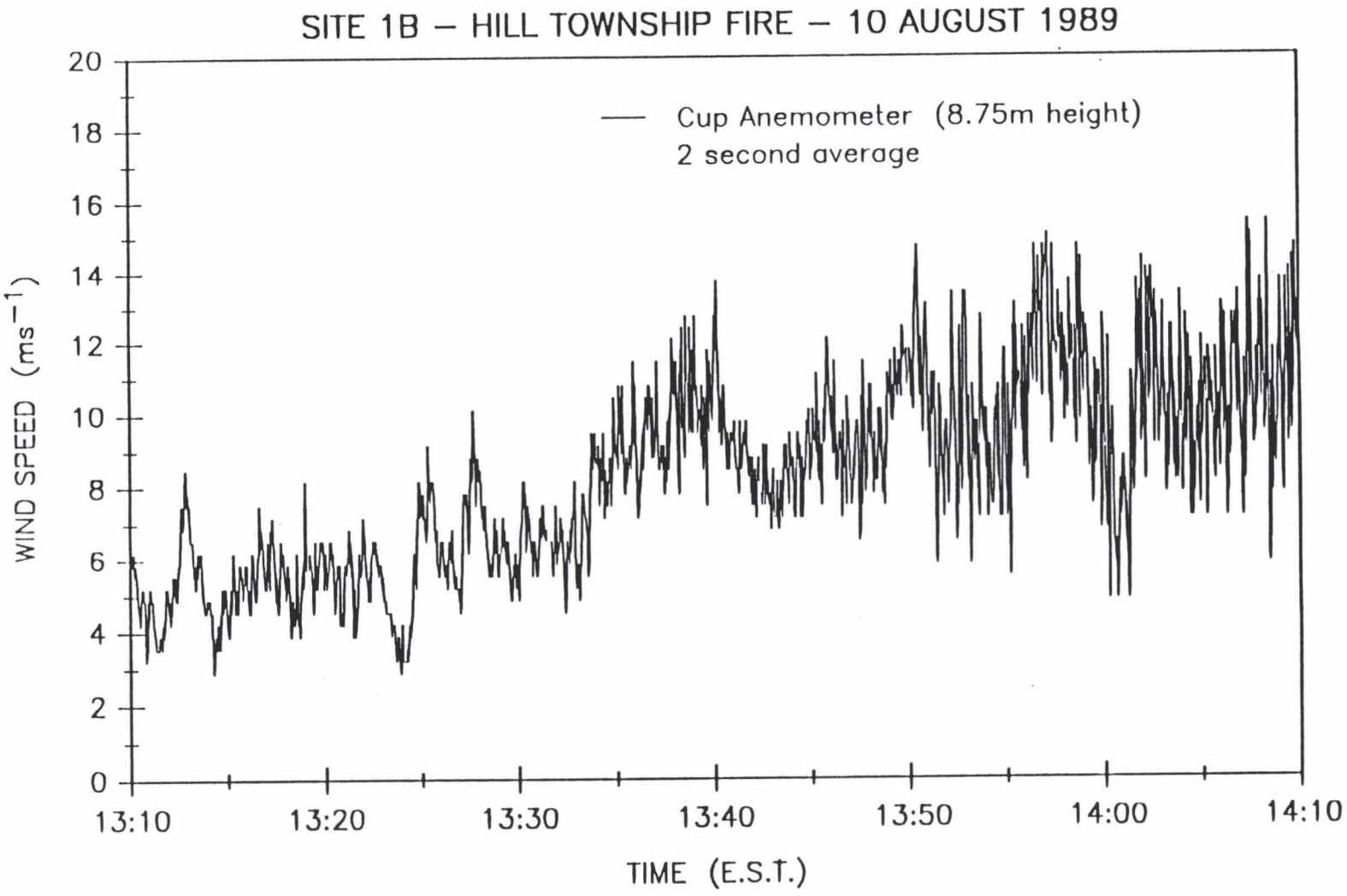
All of the horizontal wind data collected by the University of Iowa have been reduced, converted and standardized. A site map and graphs of the data follow. Their incorporation into flow field data base is underway. Some additional data from PSCR and others will be once more solicited for inclusion. Full, integrated flow integration has been done on test sets of the data, final full integration of the entire set will take place once the sets are finalized.

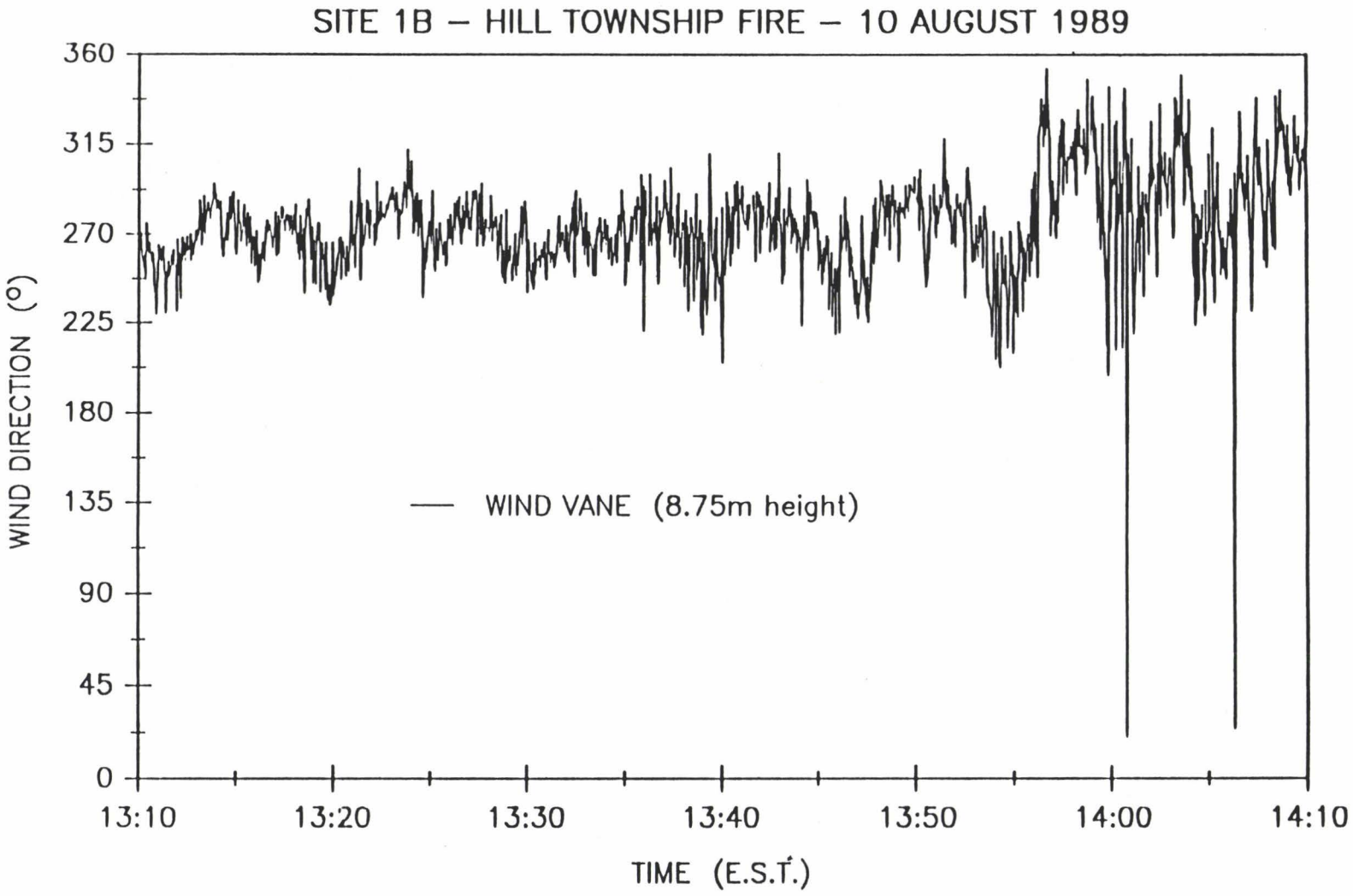
RELATIVE LOCATION OF IOWA EXPERIMENTAL TOWERS, HILL TOWNSHIP FIRE

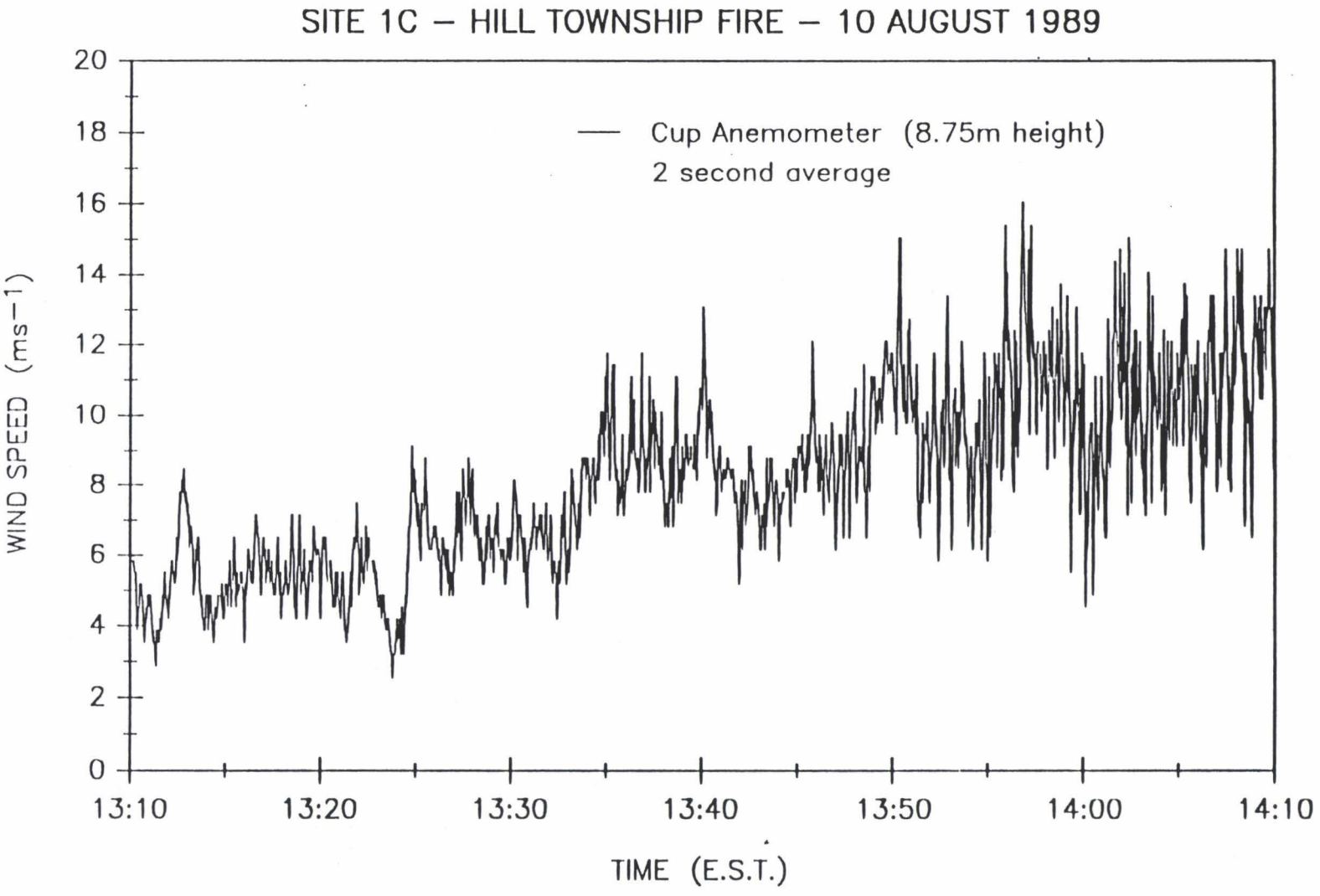


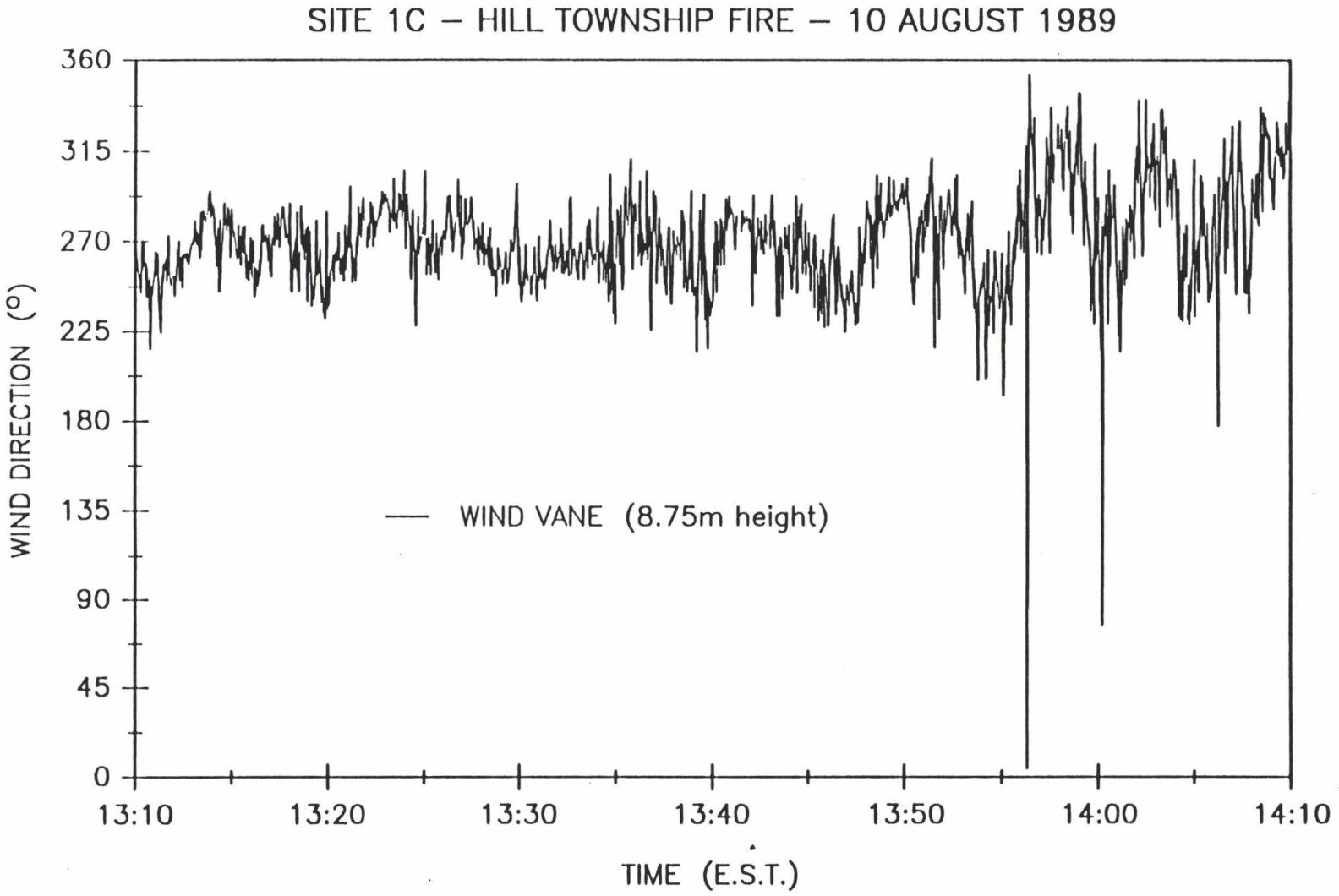

SITE 1A – HILL TOWNSHIP FIRE – 10 AUGUST 1989
Cup Anemometer (8.75m height)
2 second average
WIND SPEED (ms⁻¹)
0
2
4
6
8
10
12
14
16
18
20
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)

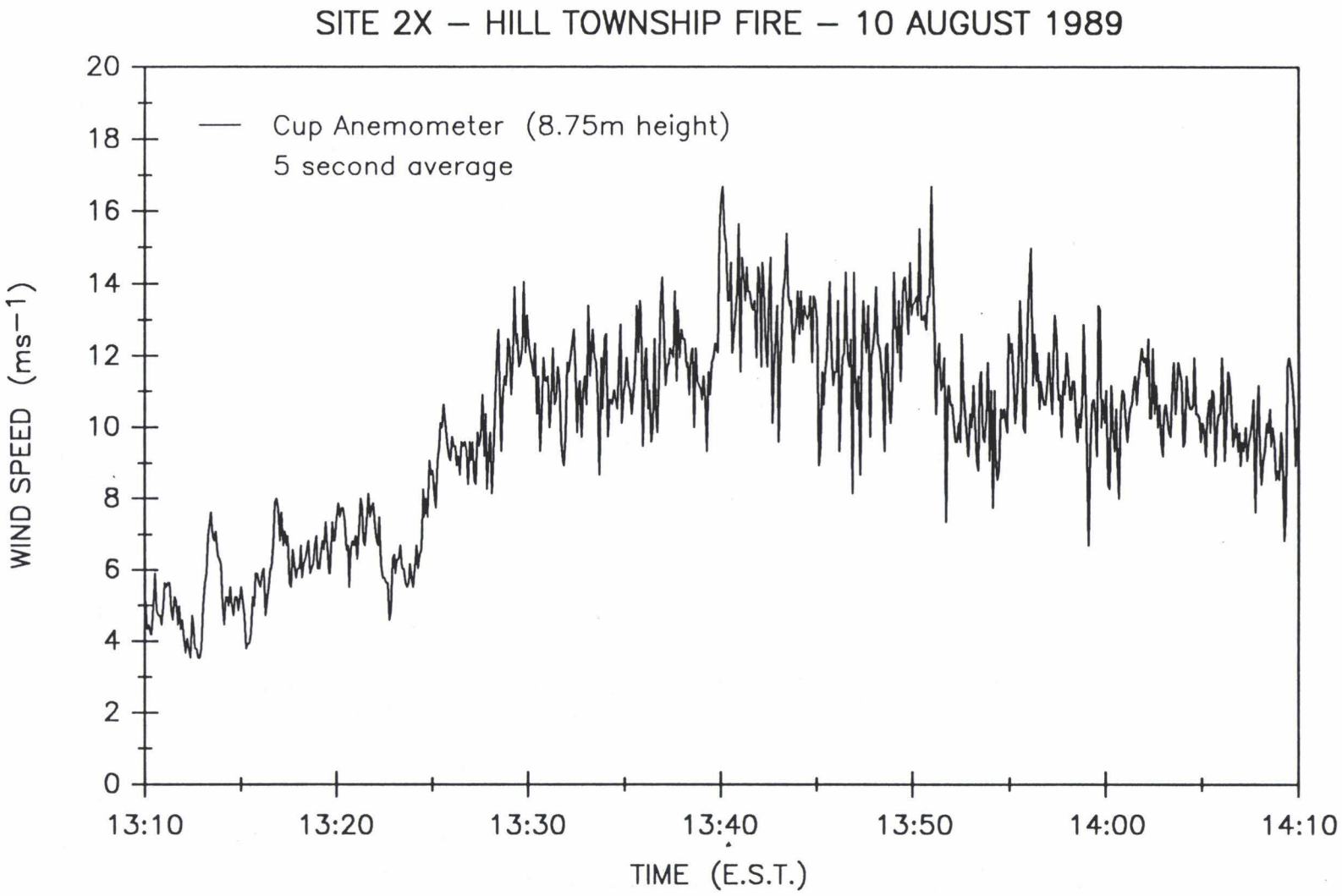

SITE 1A – HILL TOWNSHIP FIRE – 10 AUGUST 1989
360
315
270
225
180
135
90
45
0
WIND DIRECTION (°)
Wind Vane (8.75m height)
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)

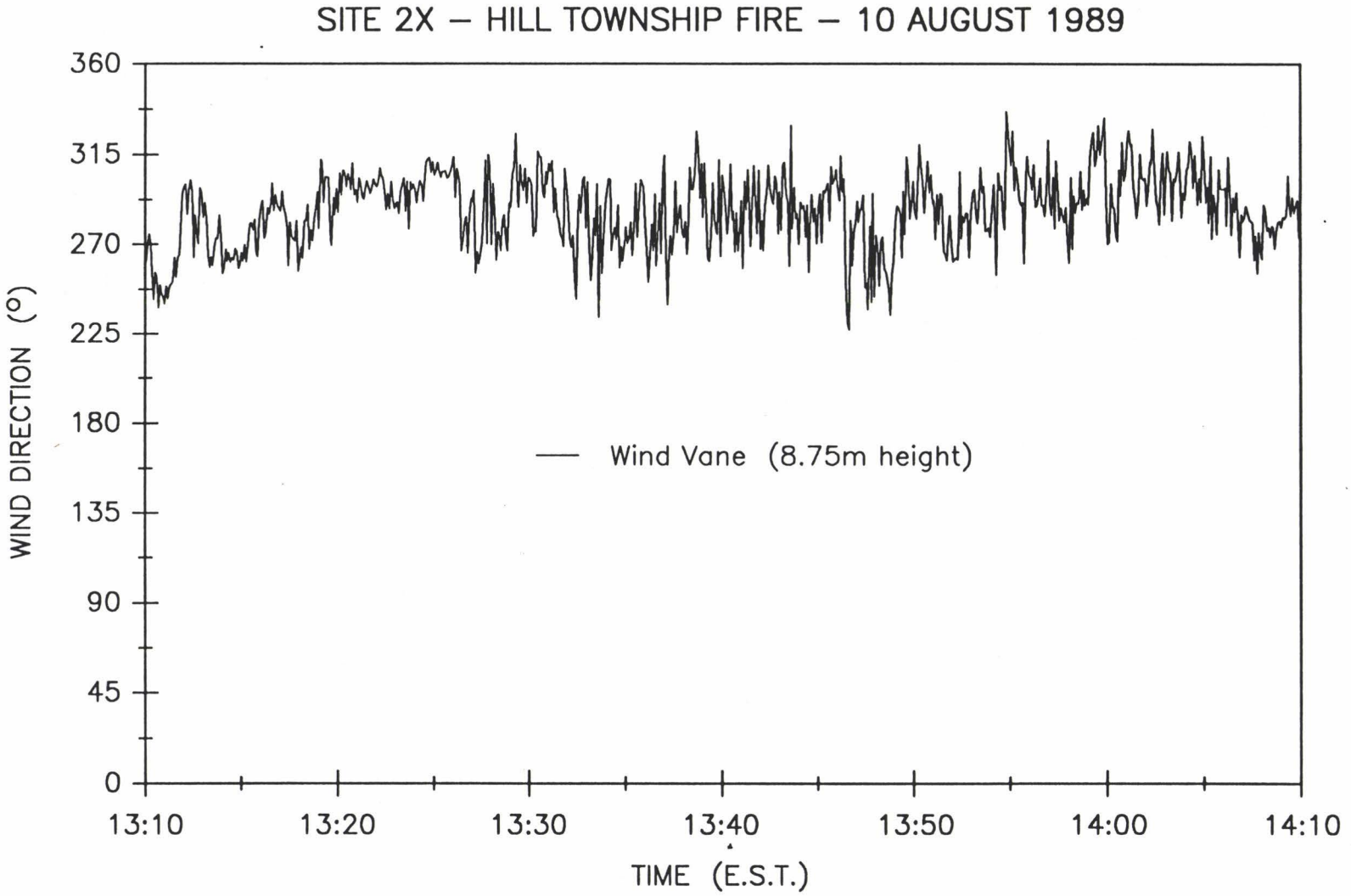

SITE 1B – HILL TOWNSHIP FIRE – 10 AUGUST 1989
Cup Anemometer (8.75m height)
2 second average
WIND SPEED (ms⁻¹)
0
2
4
6
8
10
12
14
16
18
20
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)

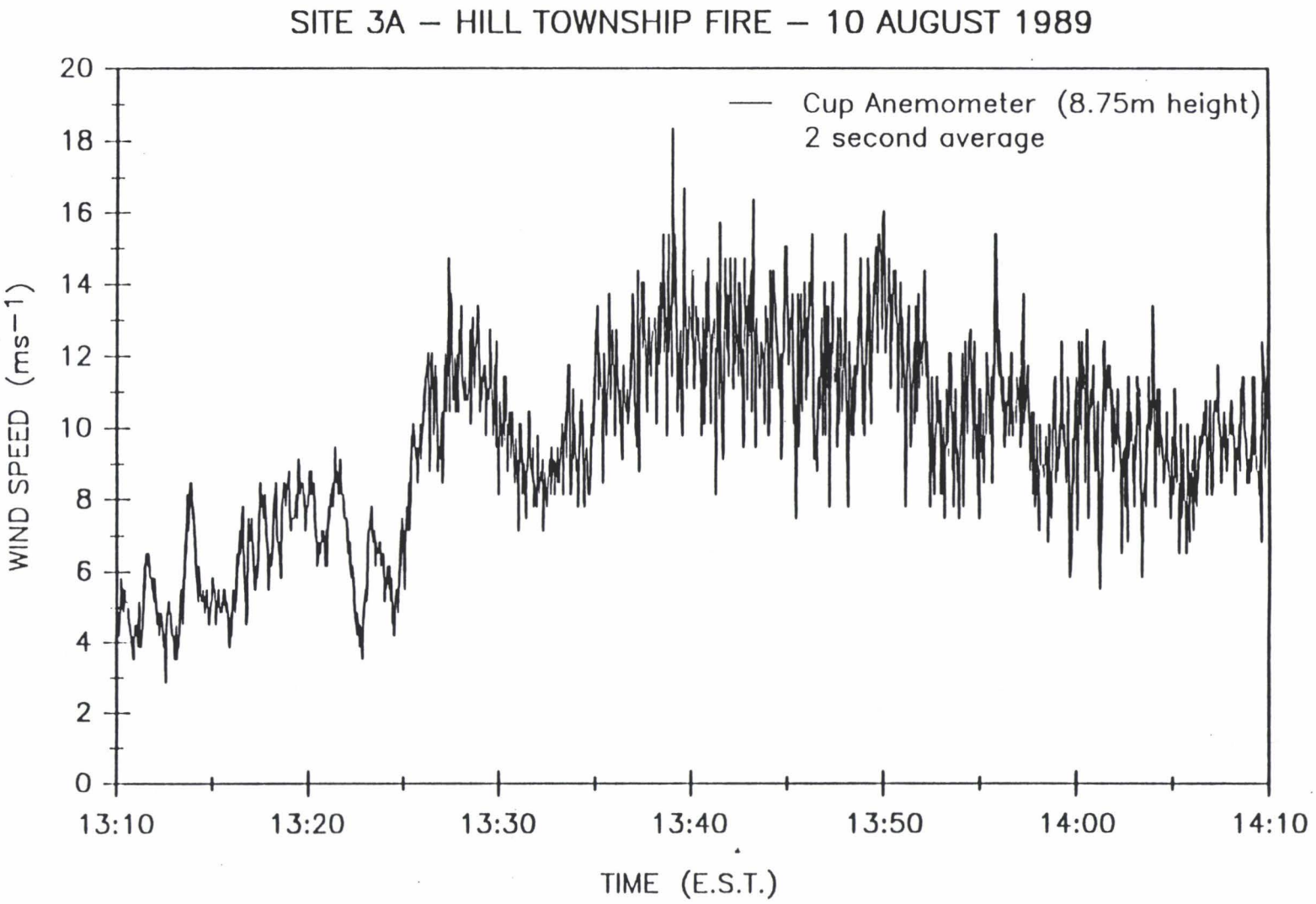

SITE 1B – HILL TOWNSHIP FIRE – 10 AUGUST 1989
360
315
270
225
180
135
90
45
0
WIND DIRECTION (°)
WIND VANE (8.75m height)
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)

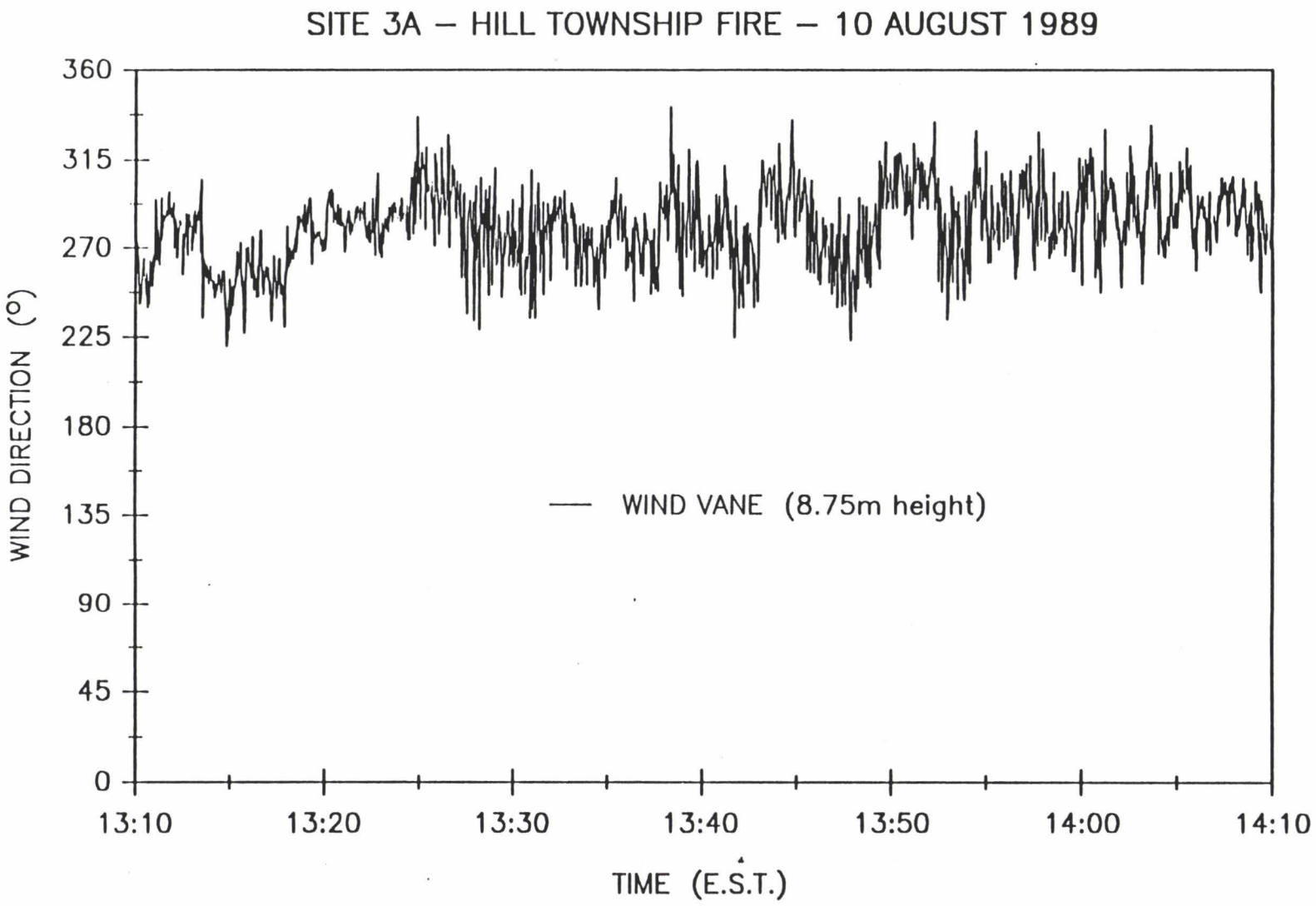

SITE 1C – HILL TOWNSHIP FIRE – 10 AUGUST 1989
Cup Anemometer (8.75m height)
2 second average
WIND SPEED (ms⁻¹)
0
2
4
6
8
10
12
14
16
18
20
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)

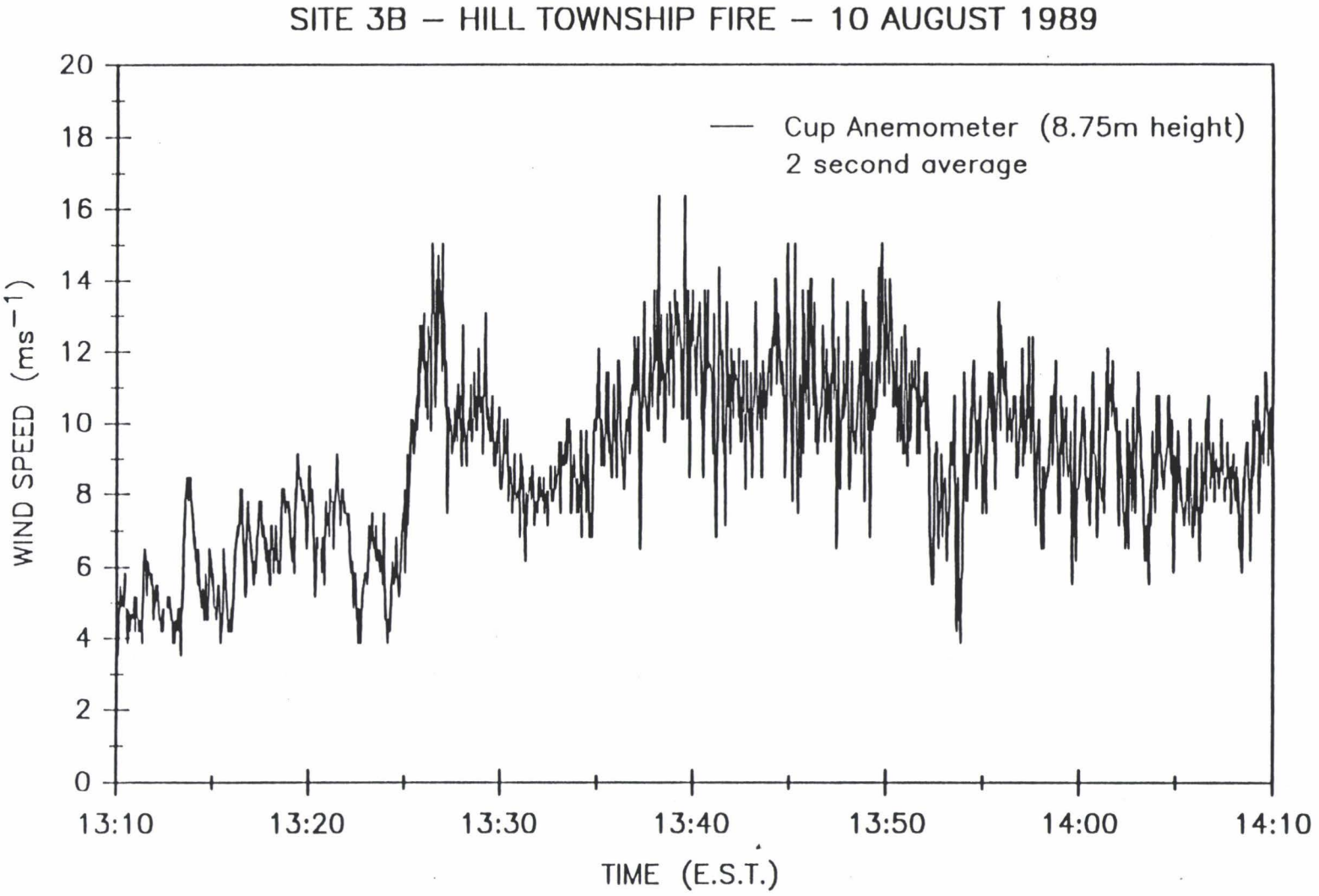

SITE 1C – HILL TOWNSHIP FIRE – 10 AUGUST 1989
360
315
270
225
180
135
90
45
0
WIND DIRECTION (°)
WIND VANE (8.75m height)
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)

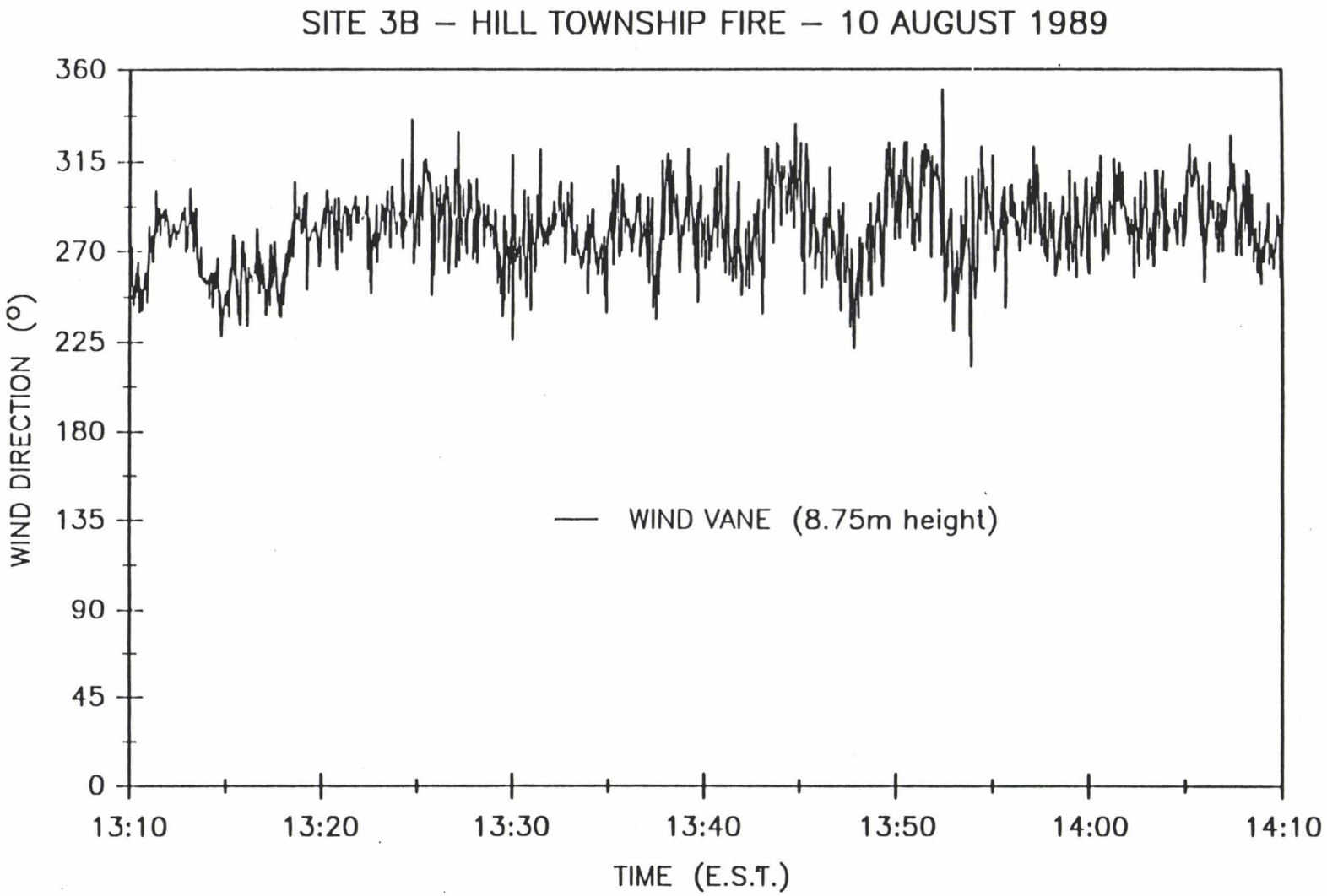

SITE 2X – HILL TOWNSHIP FIRE – 10 AUGUST 1989
Cup Anemometer (8.75m height)
5 second average
WIND SPEED (ms−1)
0
2
4
6
8
10
12
14
16
18
20
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)

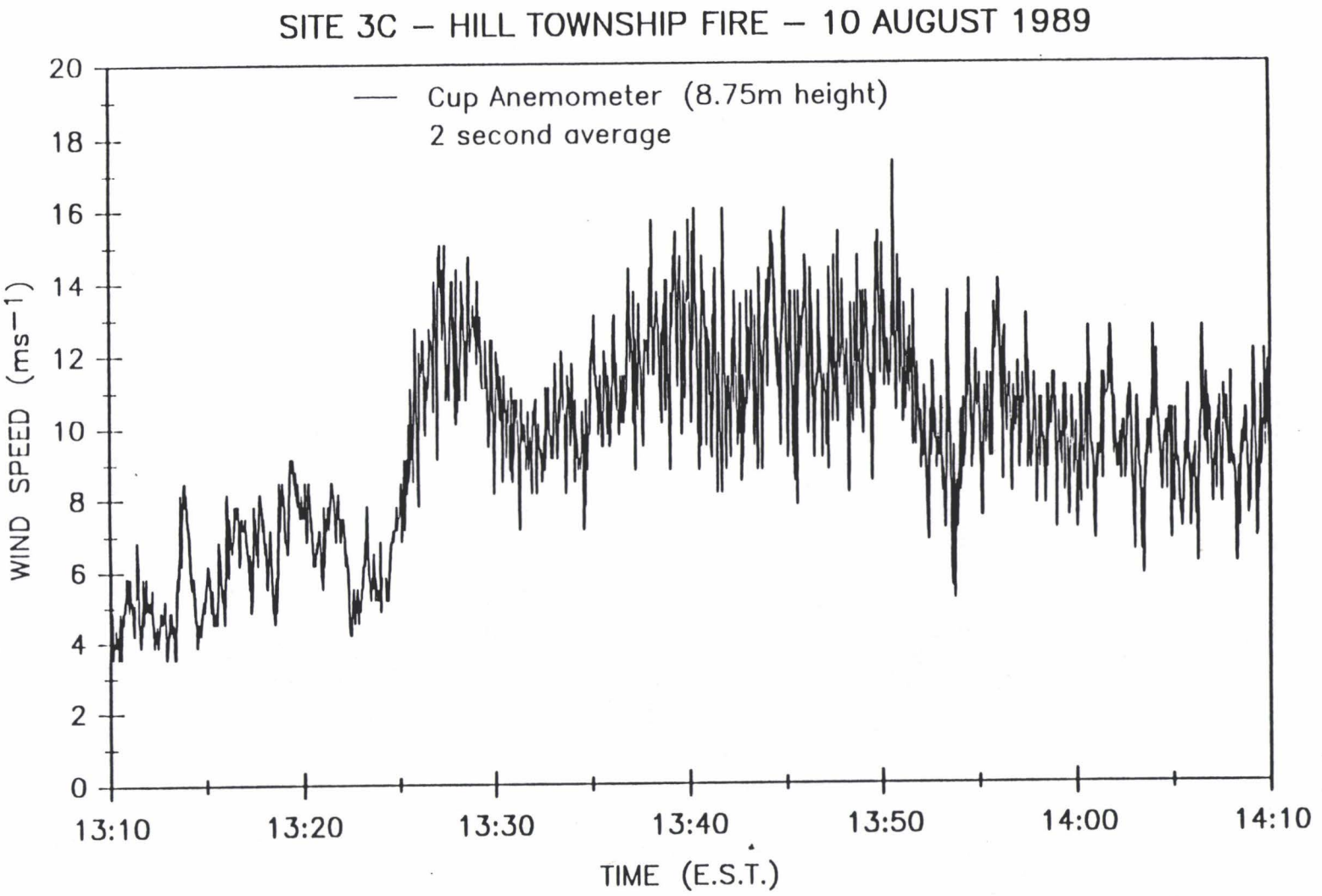

SITE 2X – HILL TOWNSHIP FIRE – 10 AUGUST 1989
WIND DIRECTION (°)
360
315
270
225
180
135
90
45
0
Wind Vane (8.75m height)
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)

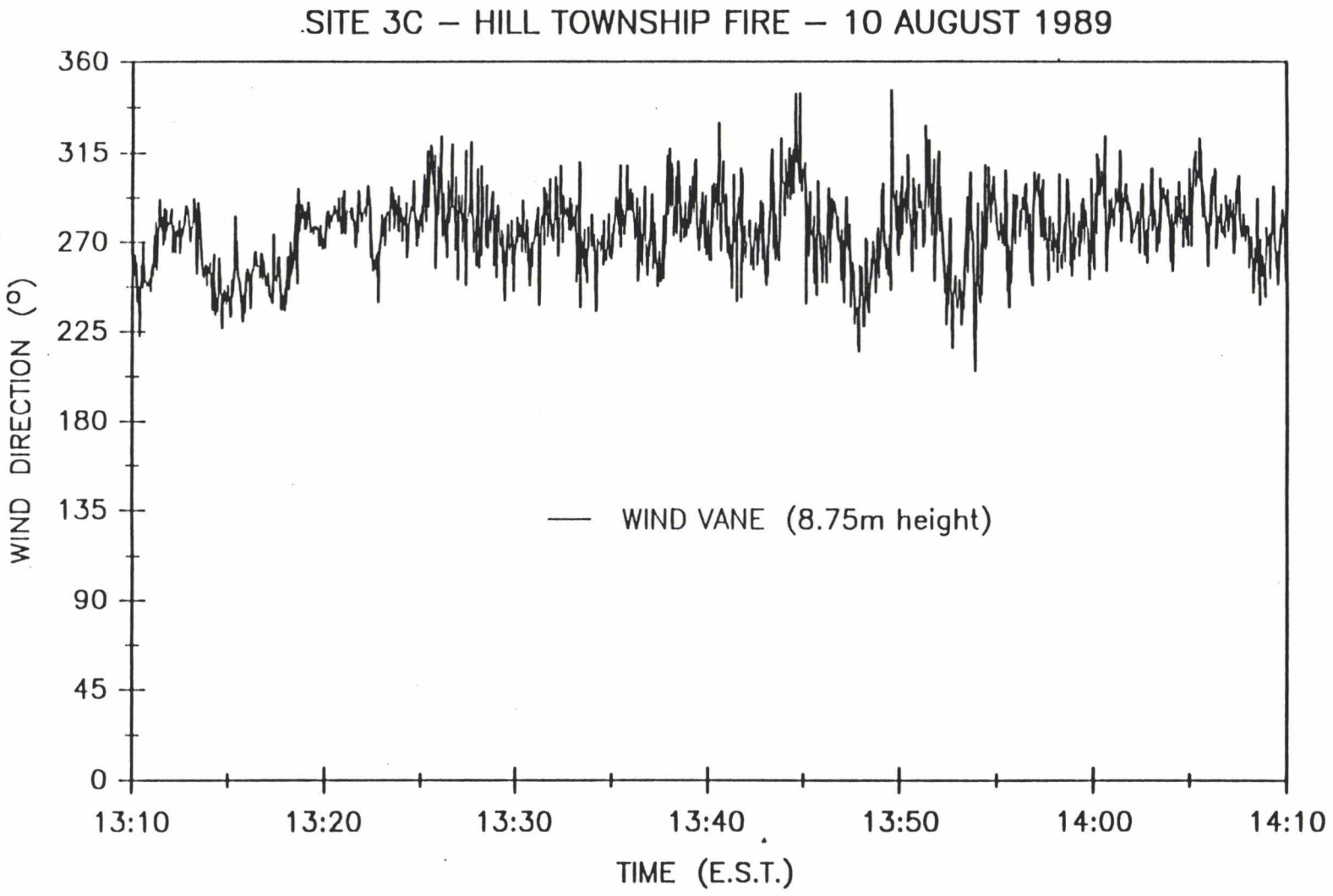

SITE 3A – HILL TOWNSHIP FIRE – 10 AUGUST 1989
Cup Anemometer (8.75m height)
2 second average
WIND SPEED (ms−1)
0
2
4
6
8
10
12
14
16
18
20
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)

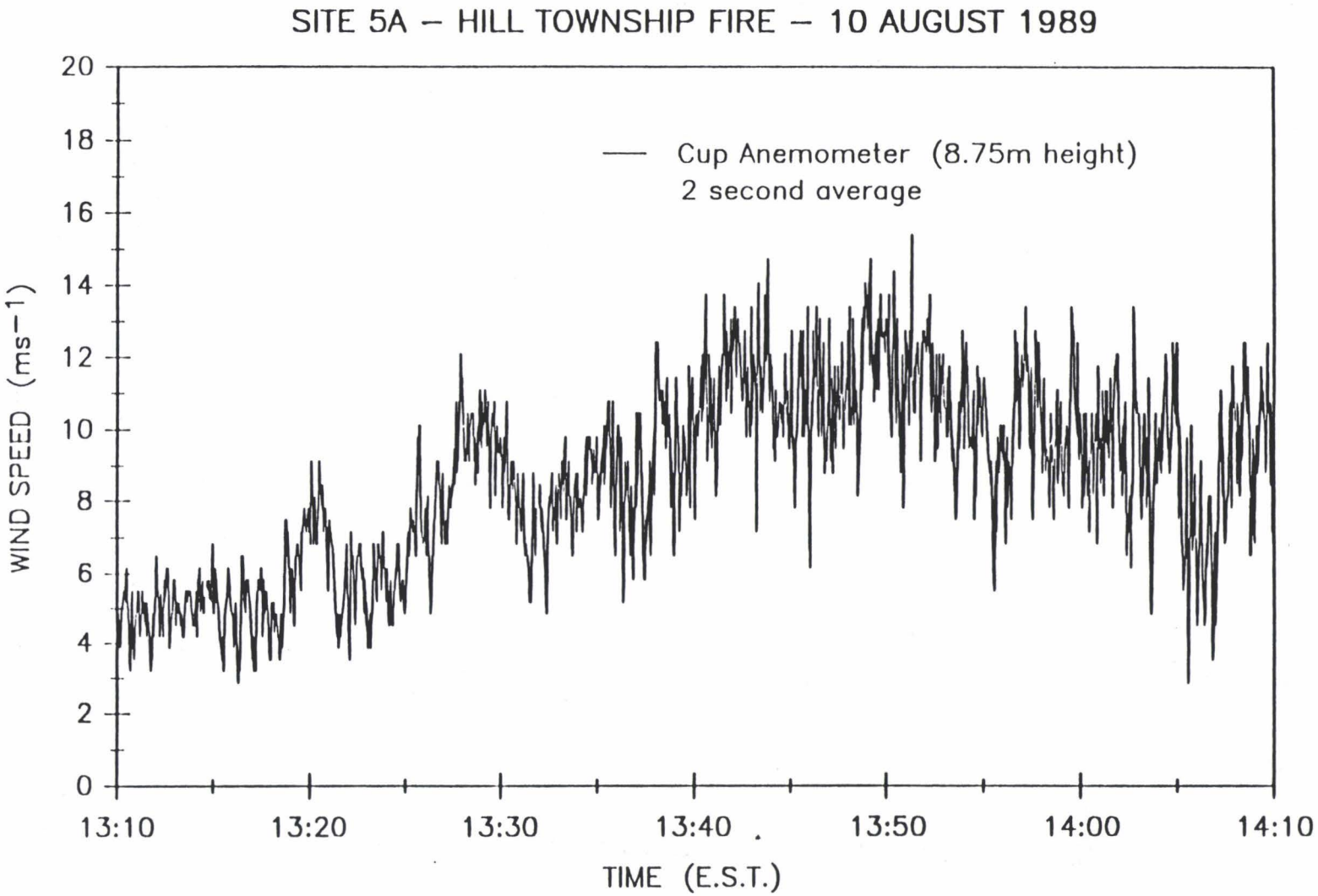

SITE 3A – HILL TOWNSHIP FIRE – 10 AUGUST 1989
360
315
270
225
180
135
90
45
0
WIND DIRECTION (°)
WIND VANE (8.75m height)
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)

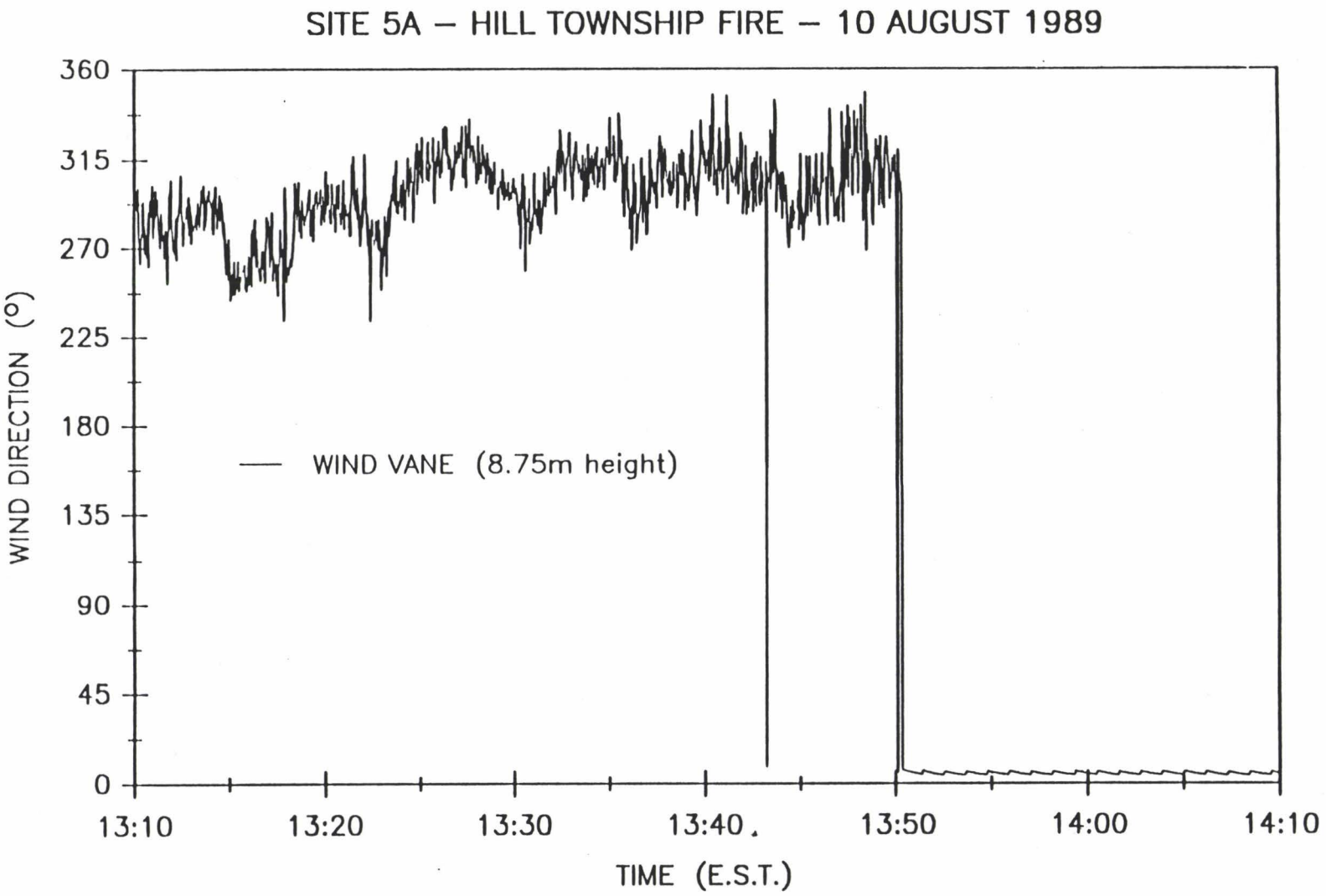

SITE 3B – HILL TOWNSHIP FIRE – 10 AUGUST 1989
Cup Anemometer (8.75m height)
2 second average
WIND SPEED (ms^{-1})
0
2
4
6
8
10
12
14
16
18
20
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)

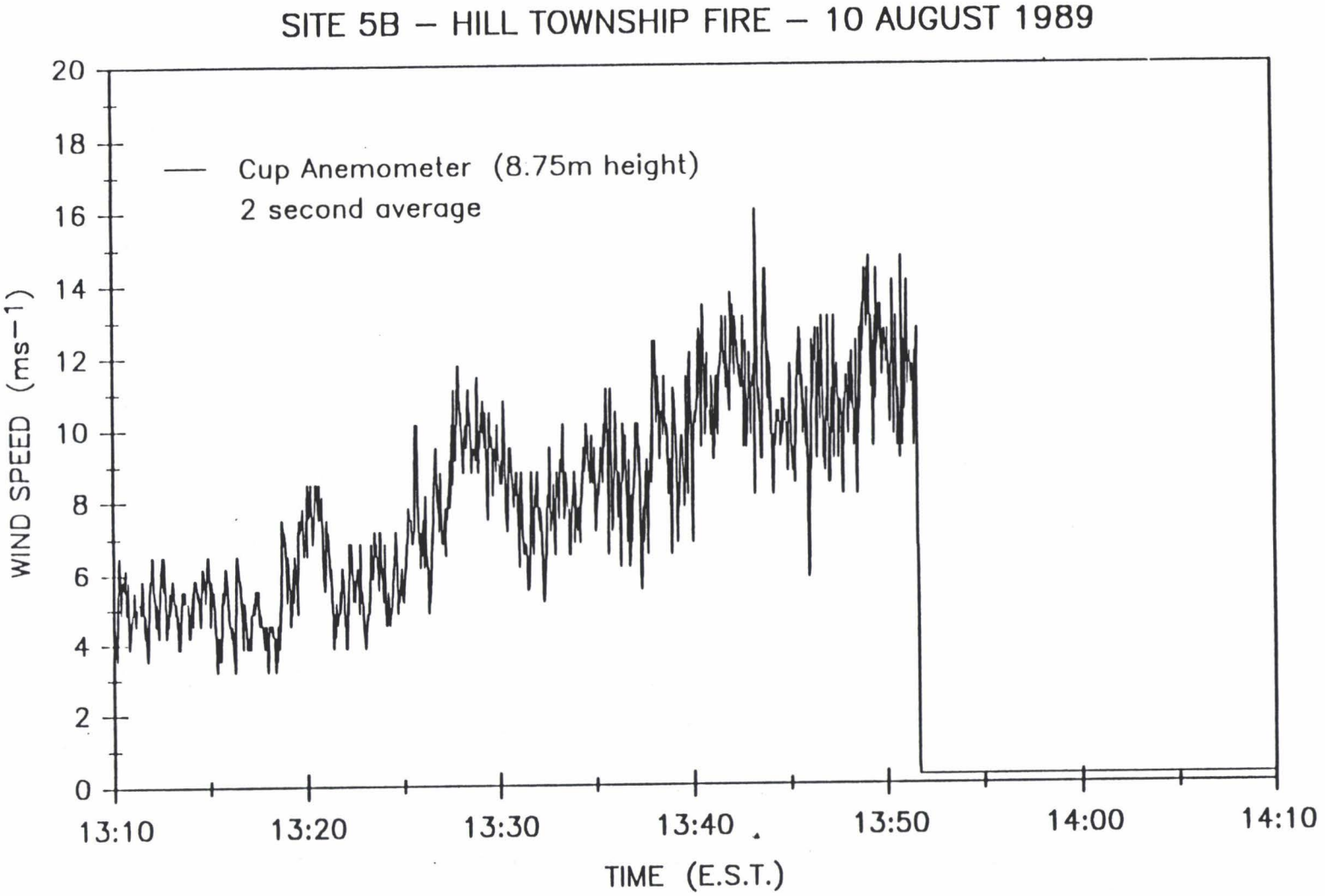

SITE 3B – HILL TOWNSHIP FIRE – 10 AUGUST 1989
360
315
270
225
180
135
90
45
0
WIND DIRECTION (°)
WIND VANE (8.75m height)
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)

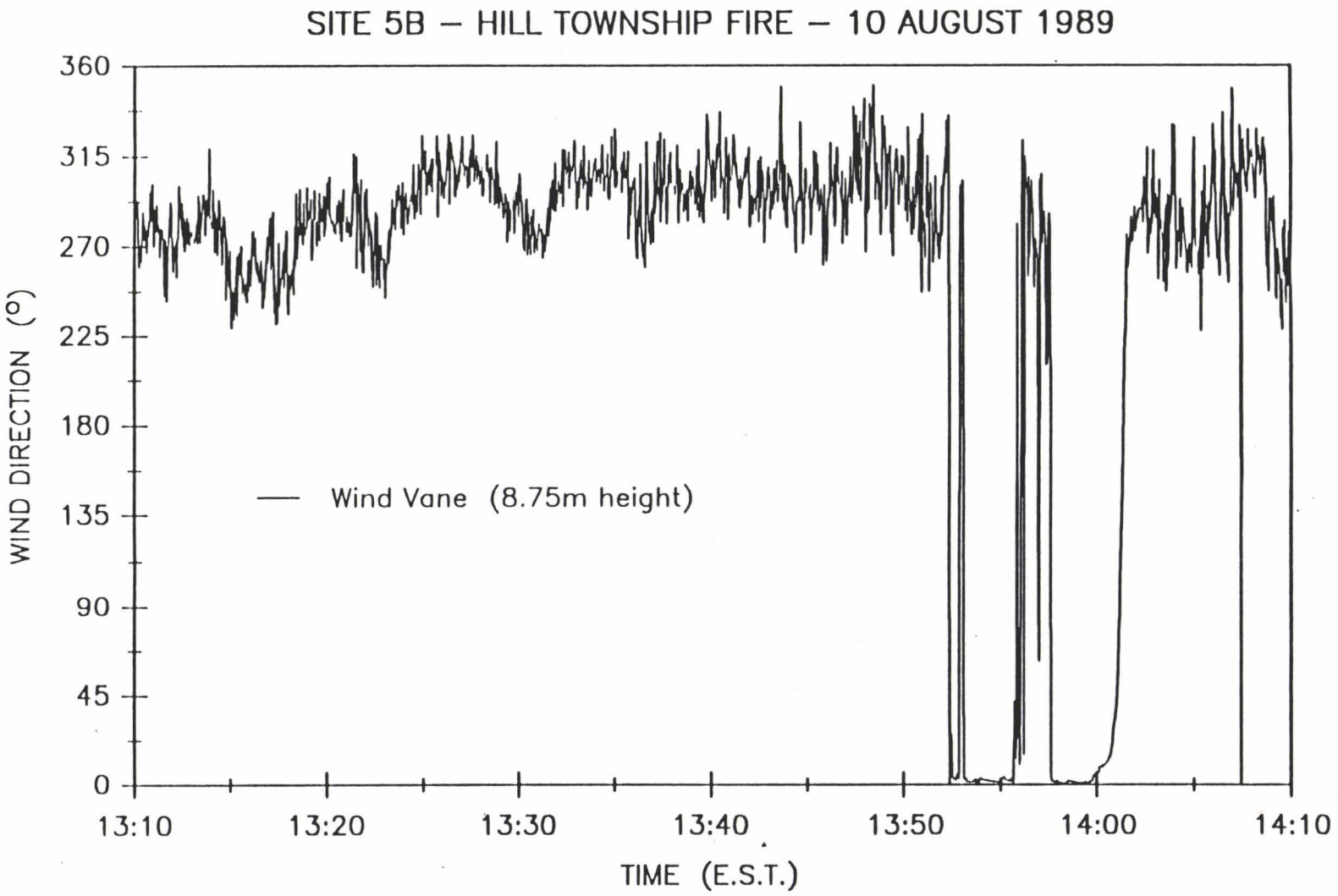

SITE 3C – HILL TOWNSHIP FIRE – 10 AUGUST 1989
Cup Anemometer (8.75m height)
2 second average
WIND SPEED (ms⁻¹)
0
2
4
6
8
10
12
14
16
18
20
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)

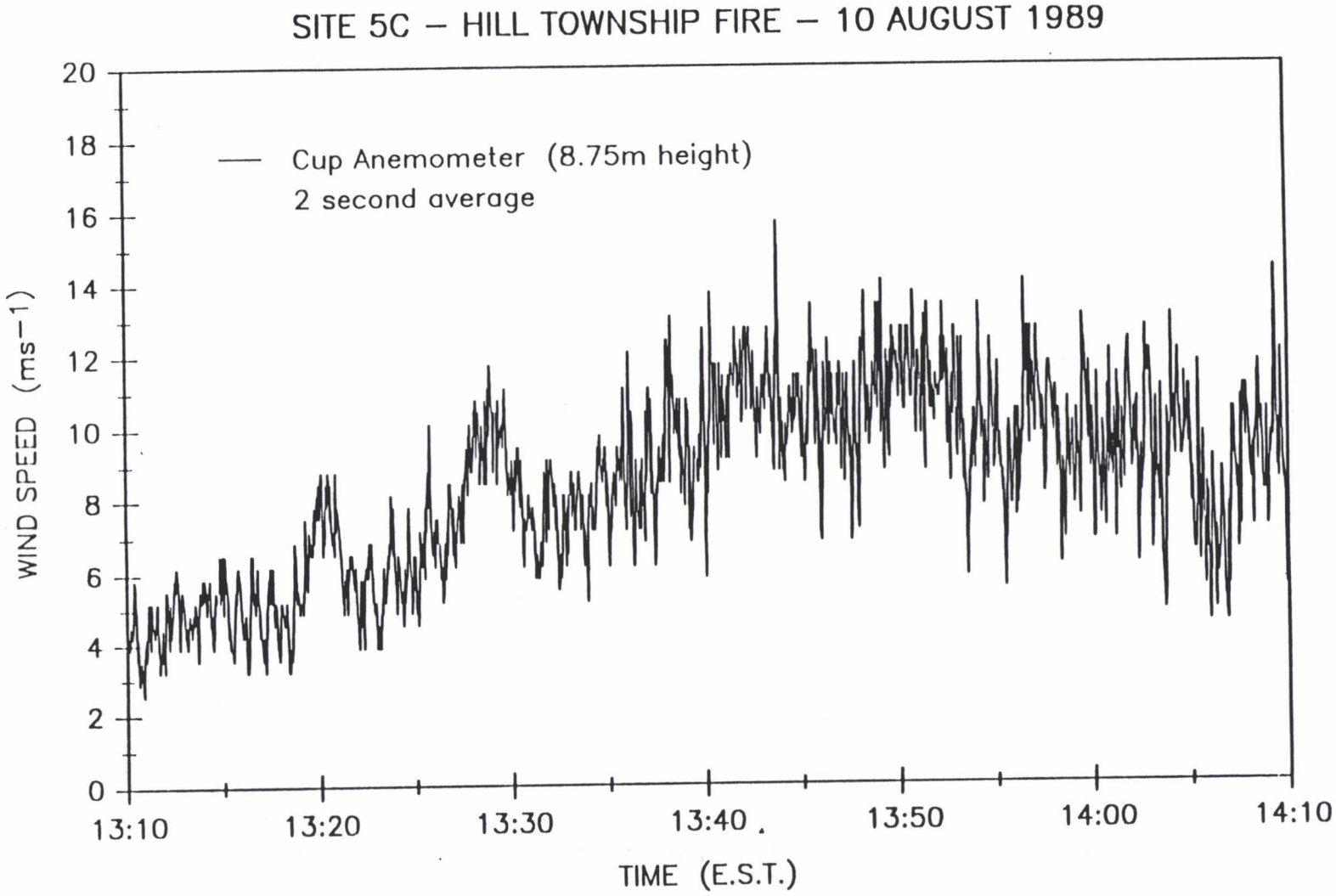

SITE 3C – HILL TOWNSHIP FIRE – 10 AUGUST 1989
360
315
270
225
180
135
90
45
0
WIND DIRECTION (°)
WIND VANE (8.75m height)
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)

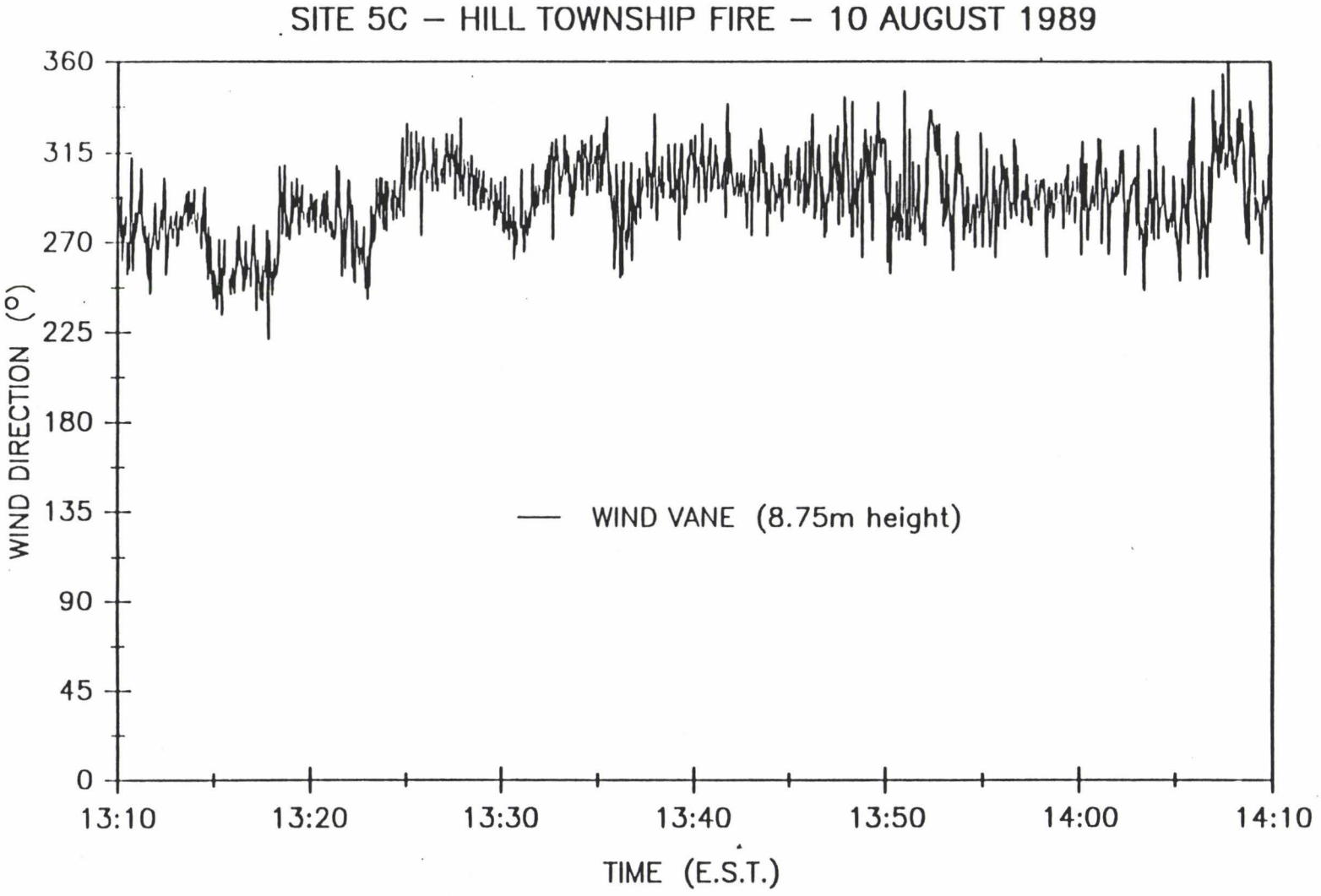

SITE 5A – HILL TOWNSHIP FIRE – 10 AUGUST 1989
Cup Anemometer (8.75m height)
2 second average
WIND SPEED (ms−1)
0
2
4
6
8
10
12
14
16
18
20
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)

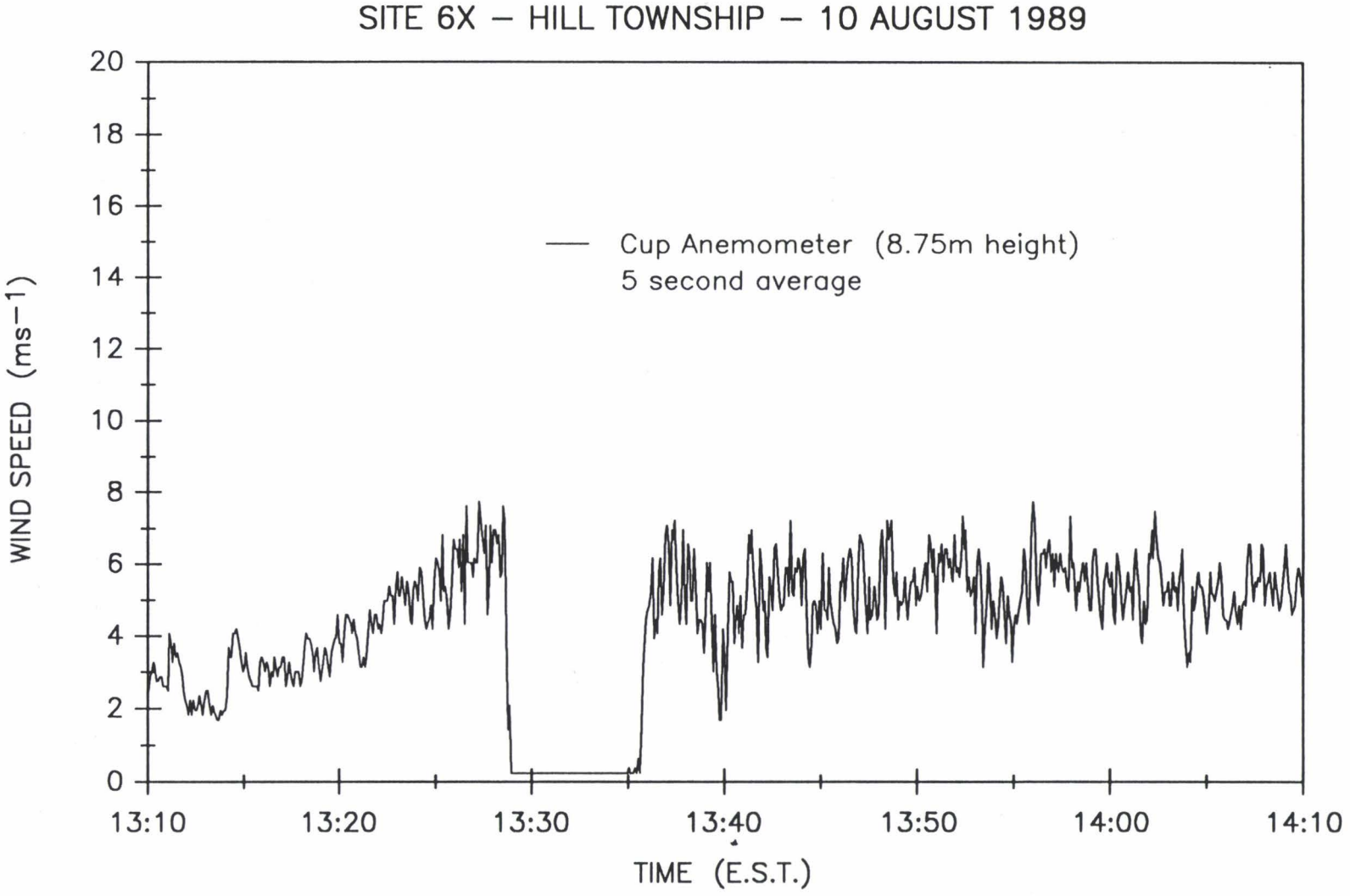

SITE 5A – HILL TOWNSHIP FIRE – 10 AUGUST 1989
360
315
270
225
180
135
90
45
0
WIND DIRECTION (°)
WIND VANE (8.75m height)
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)

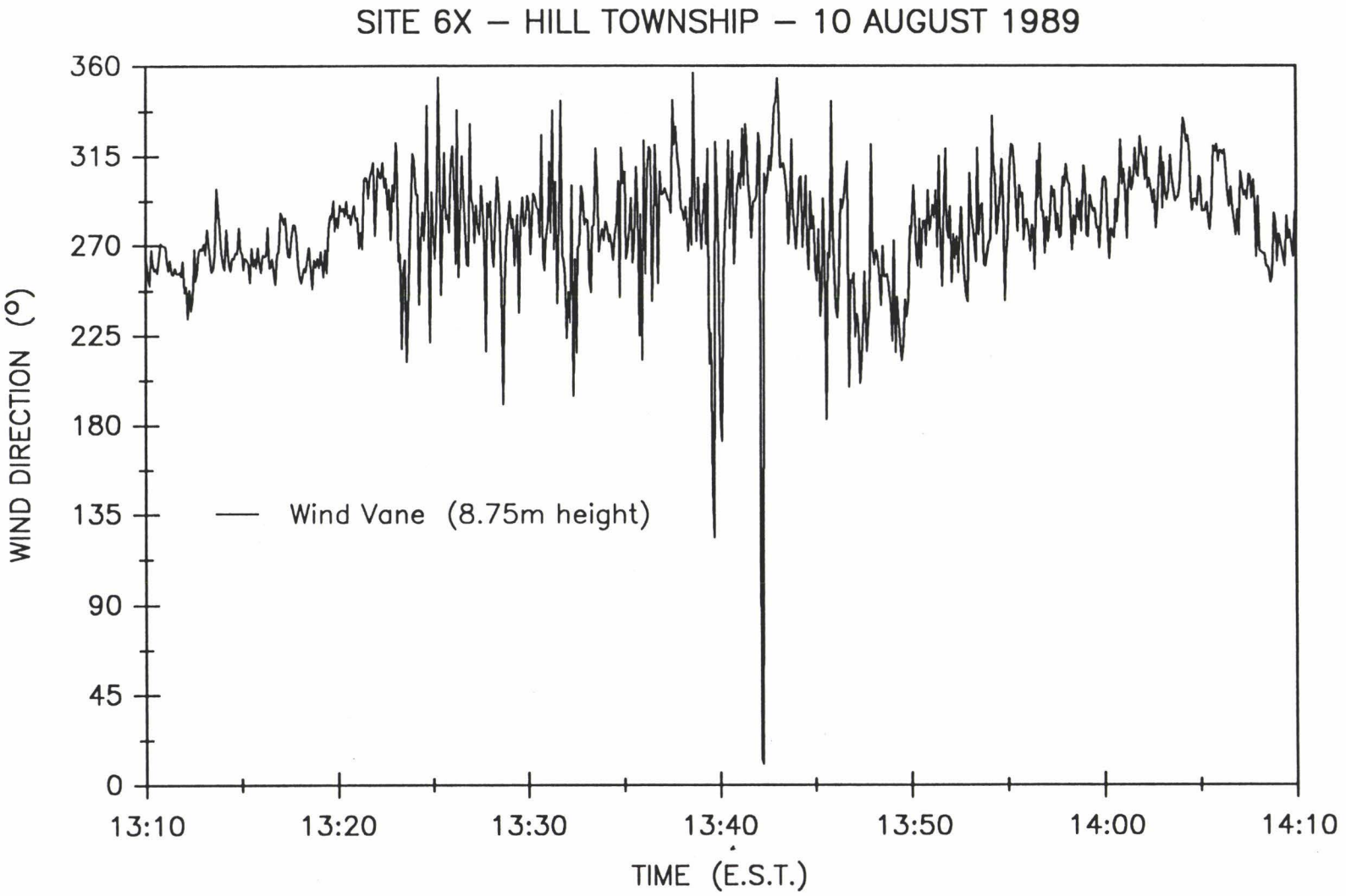

SITE 5B – HILL TOWNSHIP FIRE – 10 AUGUST 1989
Cup Anemometer (8.75m height)
2 second average
WIND SPEED (ms⁻¹)
0
2
4
6
8
10
12
14
16
18
20
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)

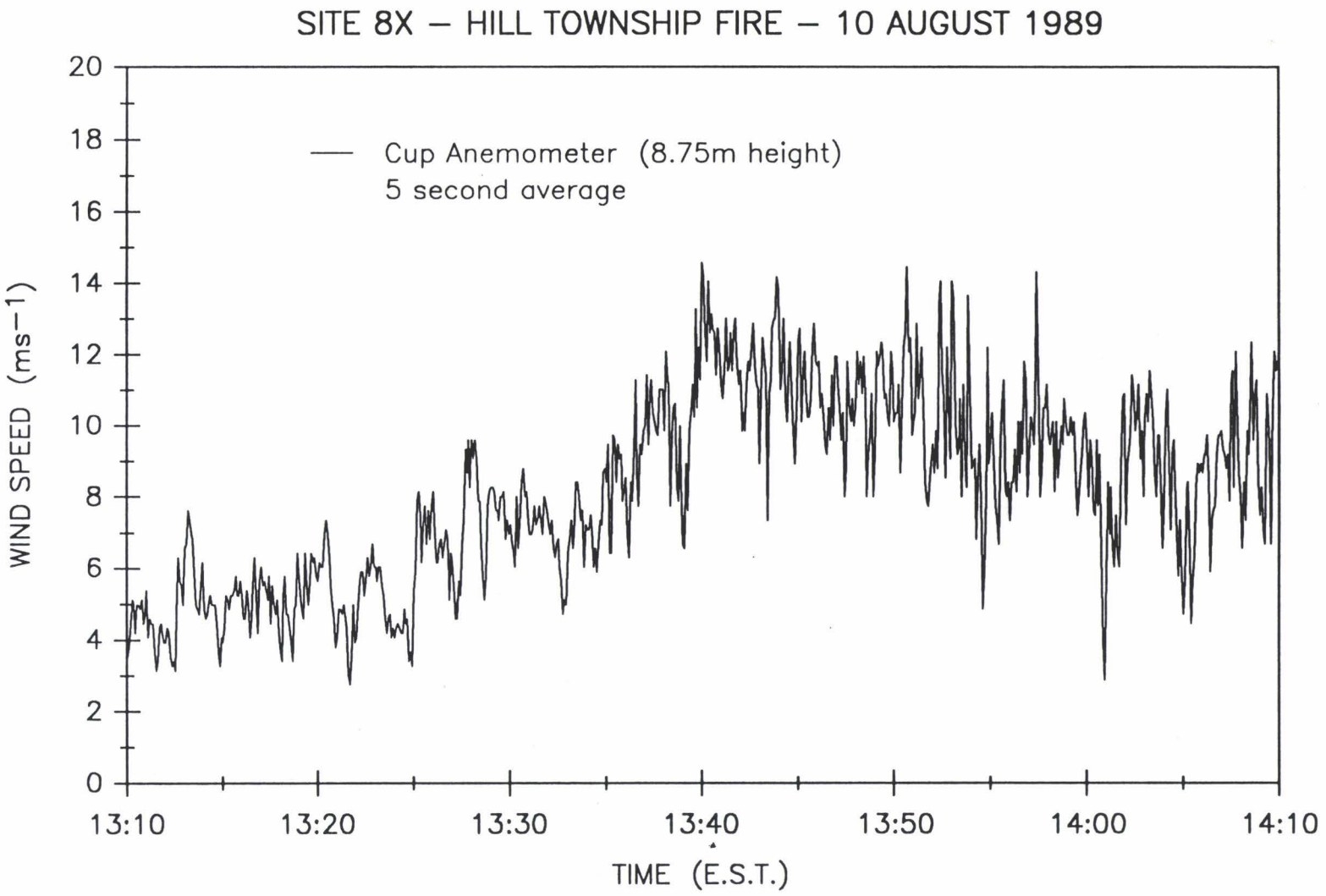

SITE 5B – HILL TOWNSHIP FIRE – 10 AUGUST 1989
360
315
270
225
180
135
90
45
0
WIND DIRECTION (°)
Wind Vane (8.75m height)
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)

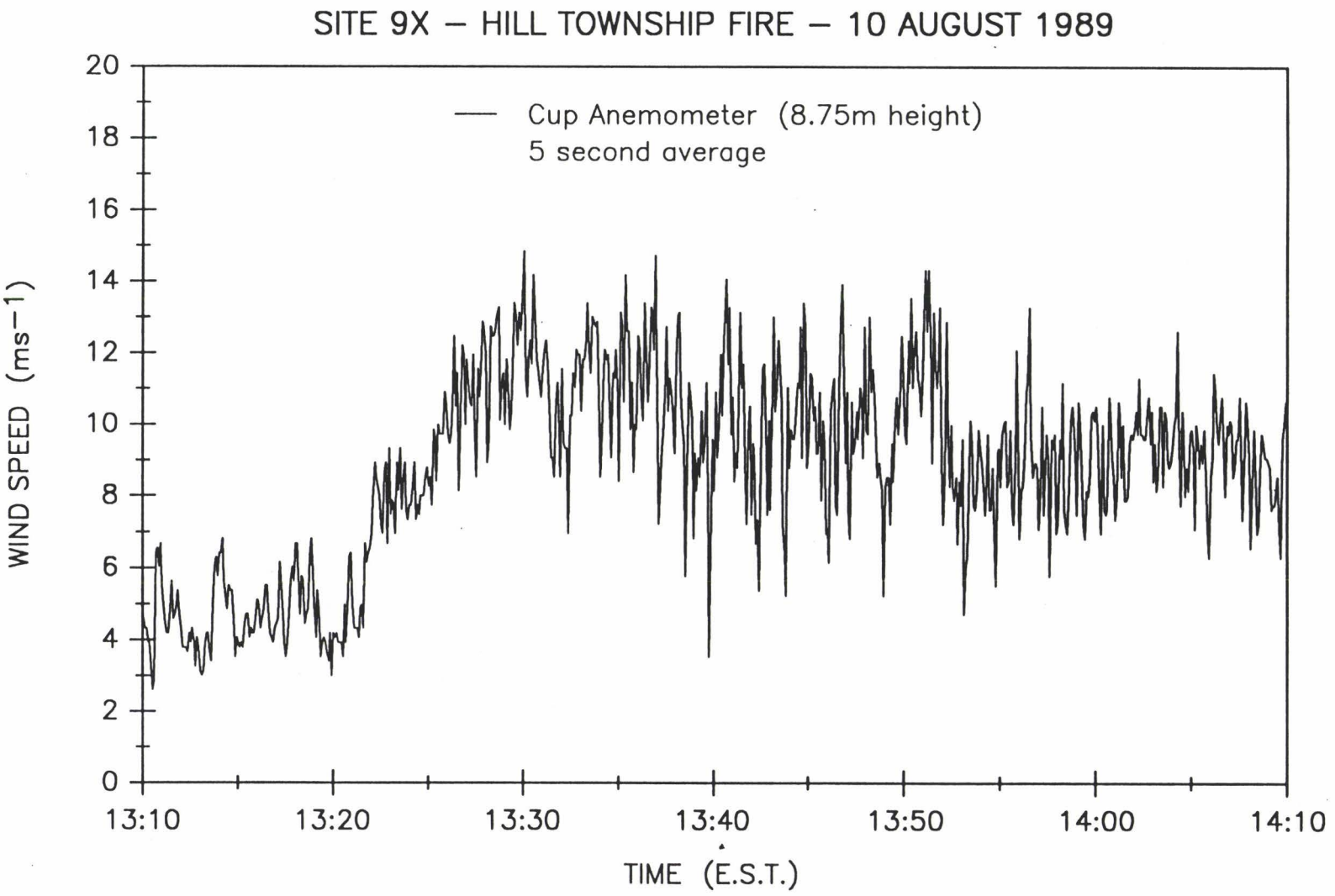

SITE 5C – HILL TOWNSHIP FIRE – 10 AUGUST 1989
Cup Anemometer (8.75m height)
2 second average
WIND SPEED (ms−1)
20
18
16
14
12
10
8
6
4
2
0
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)


SITE 5C – HILL TOWNSHIP FIRE – 10 AUGUST 1989
360
315
270
225
180
135
90
45
0
WIND DIRECTION (°)
WIND VANE (8.75m height)
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)


SITE 6X – HILL TOWNSHIP – 10 AUGUST 1989
WIND SPEED (ms−1)
20
18
16
14
12
10
8
6
4
2
0
Cup Anemometer (8.75m height)
5 second average
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)


SITE 6X – HILL TOWNSHIP – 10 AUGUST 1989
WIND DIRECTION (°)
360
315
270
225
180
135
90
45
0
Wind Vane (8.75m height)
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)


SITE 8X – HILL TOWNSHIP FIRE – 10 AUGUST 1989
Cup Anemometer (8.75m height)
5 second average
WIND SPEED (ms−1)
20
18
16
14
12
10
8
6
4
2
0
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)


SITE 9X – HILL TOWNSHIP FIRE – 10 AUGUST 1989
Cup Anemometer (8.75m height)
5 second average
WIND SPEED (ms⁻¹)
20
18
16
14
12
10
8
6
4
2
0
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)

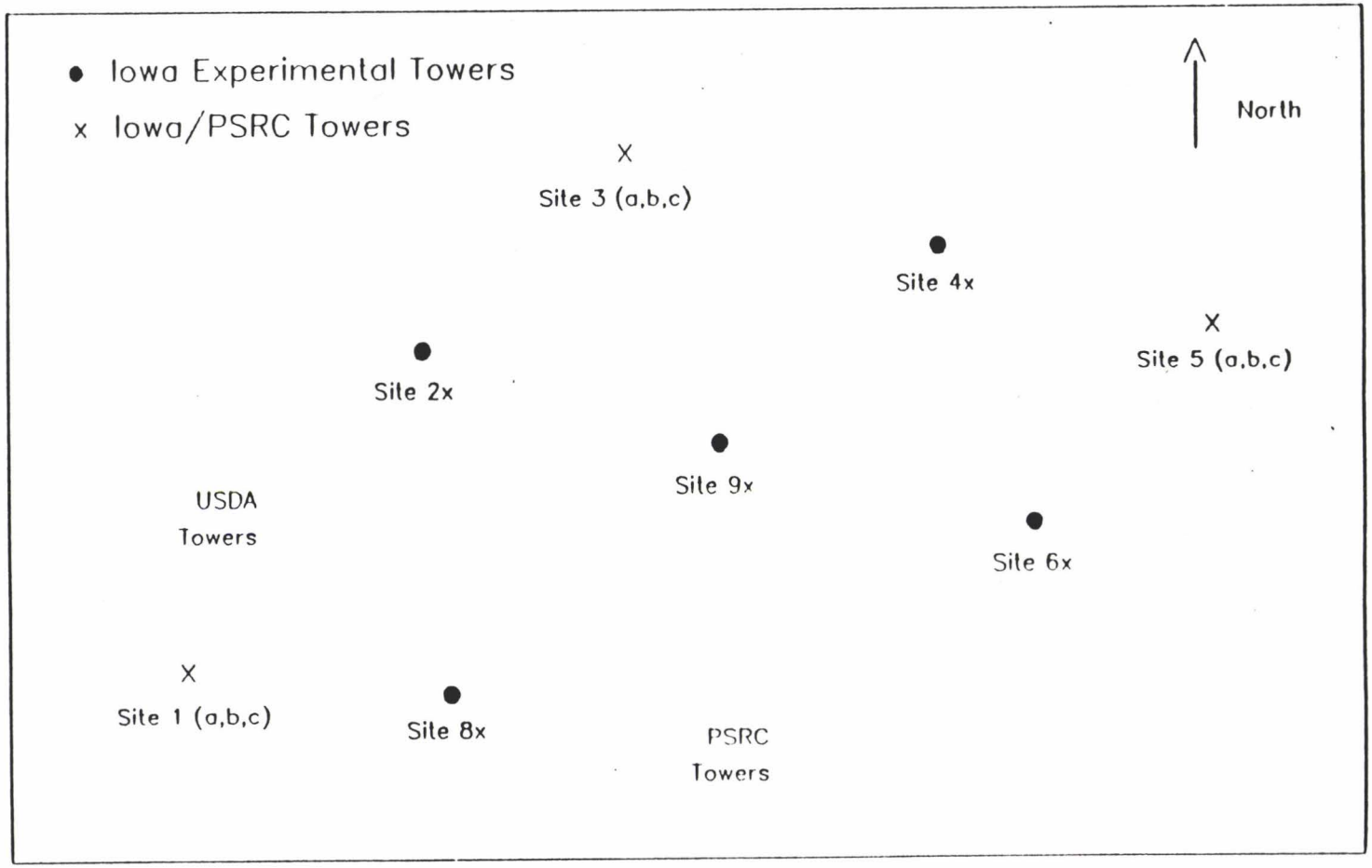
GOAL 2 (OBJECTIVE F)

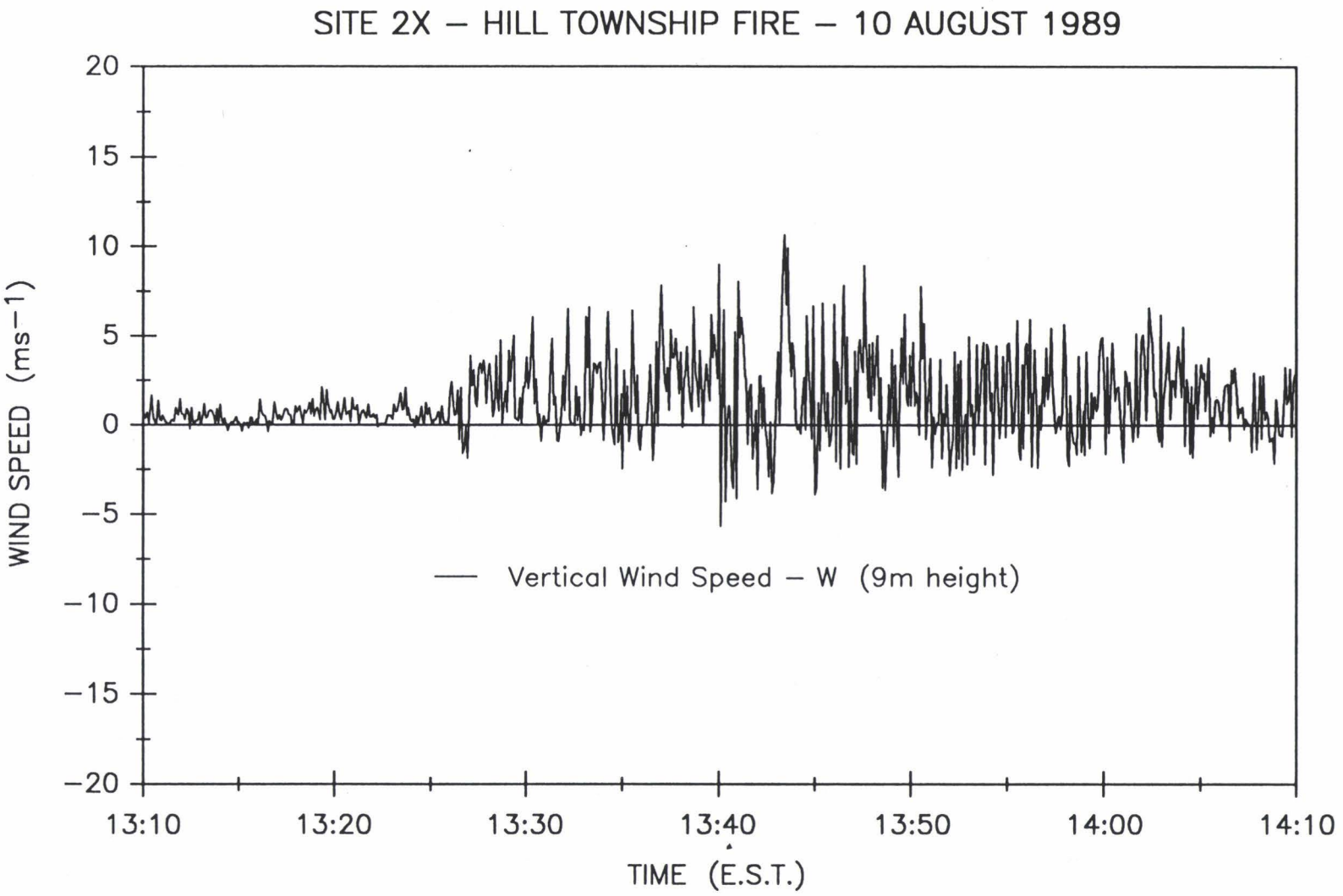
TO CHARACTERIZE THE OVERALL VERTICAL WIND FIELD AND ASPECTS OF THE 3-D FLOW FIELD IN THE FIRE USING THE U-V-W (TRIAXIAL) ANEMOMETERS

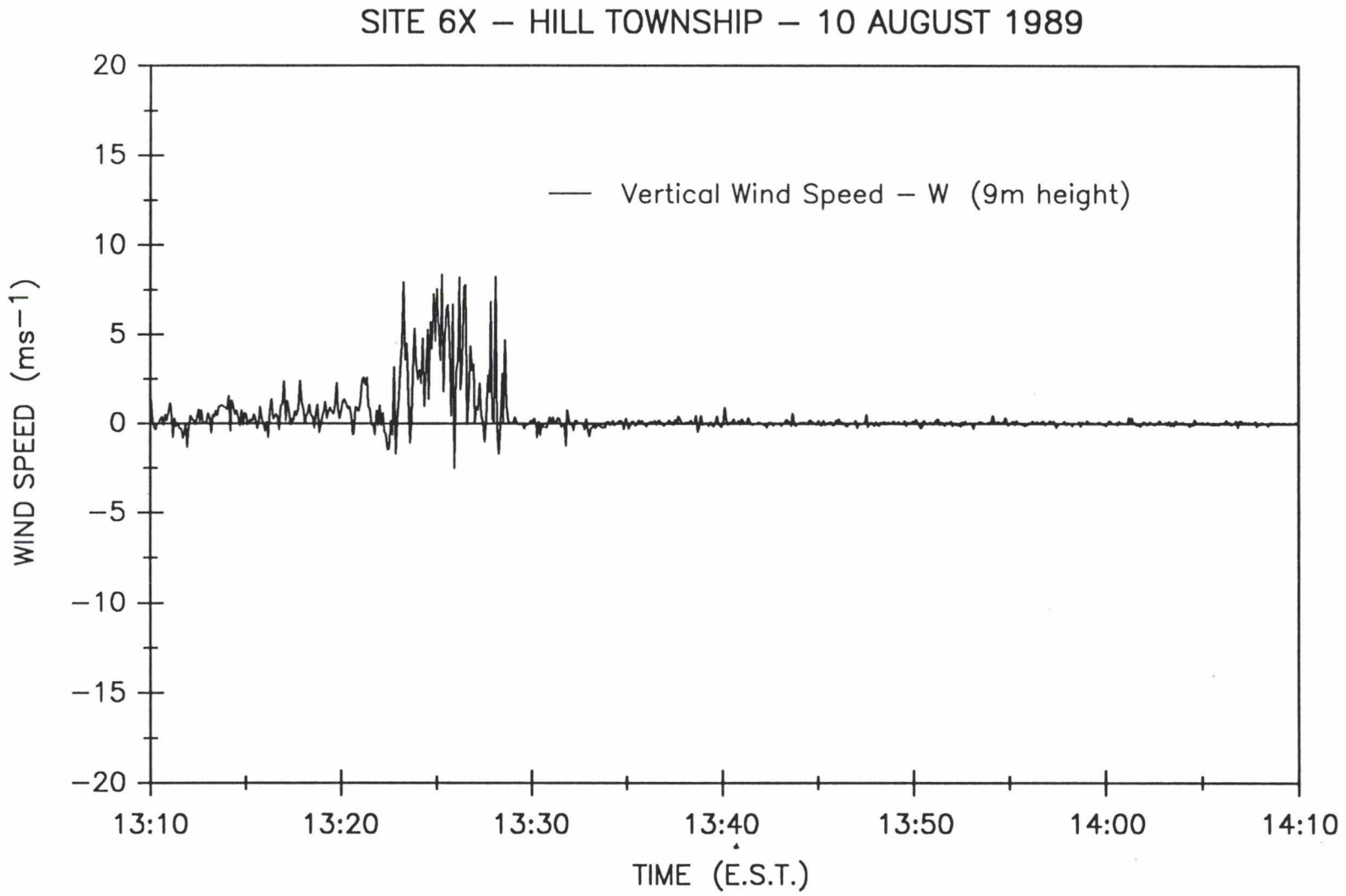
PROGRESS TO DATE:

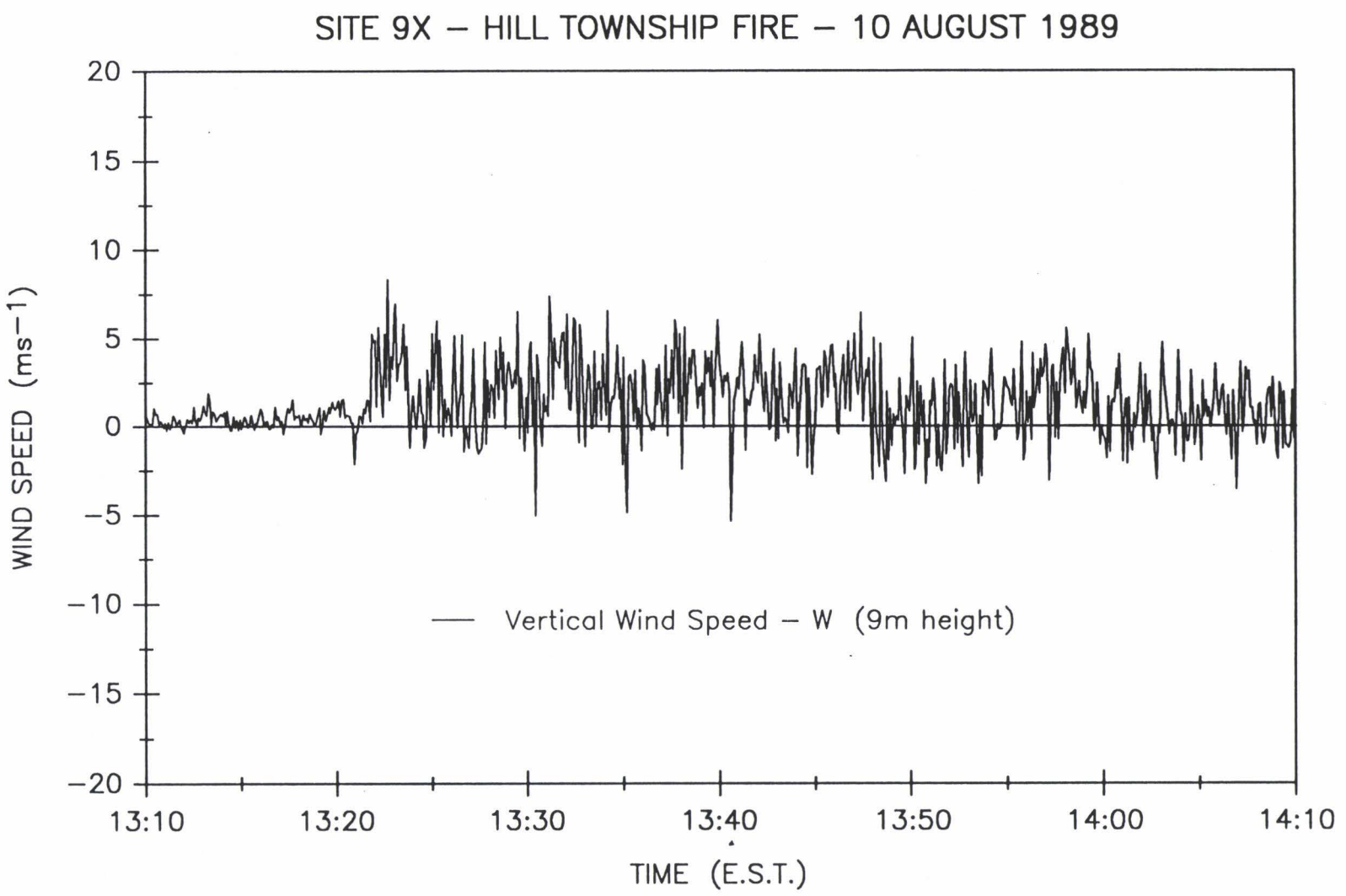
The failure of the PSRC specified thermal anemometers (see goal 6 (objective J) left the Iowa vertical sensors and the USFS vertical sensors as the only operational units in the fire. The output from the vertical uvw's is provided here. A more detailed analysis and integration will be undertaken when the full flow field is completed.

RELATIVE LOCATION OF IOWA EXPERIMENTAL TOWERS, HILL TOWNSHIP FIRE




SITE 2X – HILL TOWNSHIP FIRE – 10 AUGUST 1989
WIND SPEED (ms−1)
20
15
10
5
0
−5
−10
−15
−20
Vertical Wind Speed – W (9m height)
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)


SITE 6X – HILL TOWNSHIP – 10 AUGUST 1989
Vertical Wind Speed – W (9m height)
WIND SPEED (ms⁻¹)
20
15
10
5
0
−5
−10
−15
−20
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)


SITE 9X – HILL TOWNSHIP FIRE – 10 AUGUST 1989
WIND SPEED (ms⁻¹)
20
15
10
5
0
−5
−10
−15
−20
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)
Vertical Wind Speed – W (9m height)

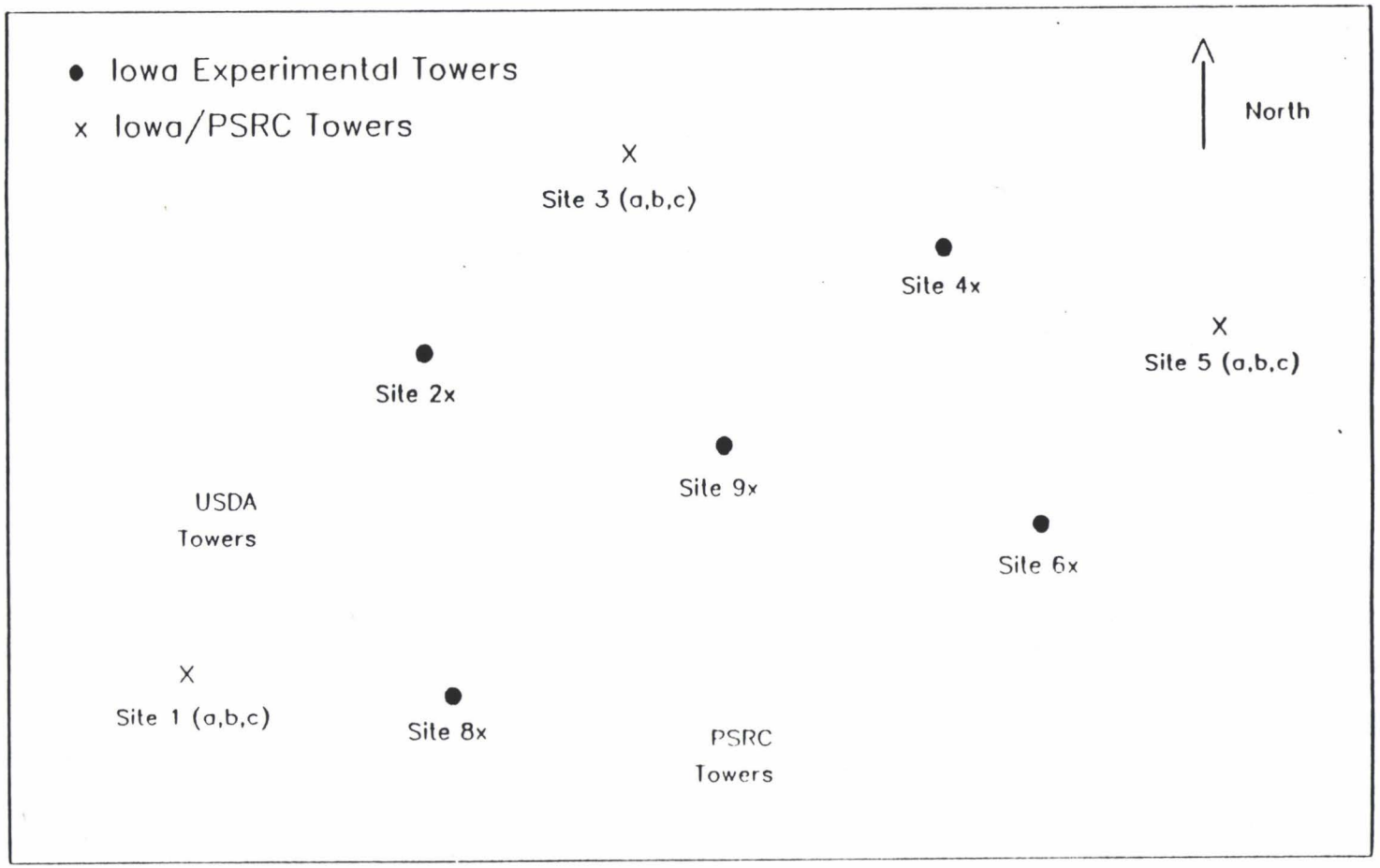
GOAL 3 (OBJECTIVE G)

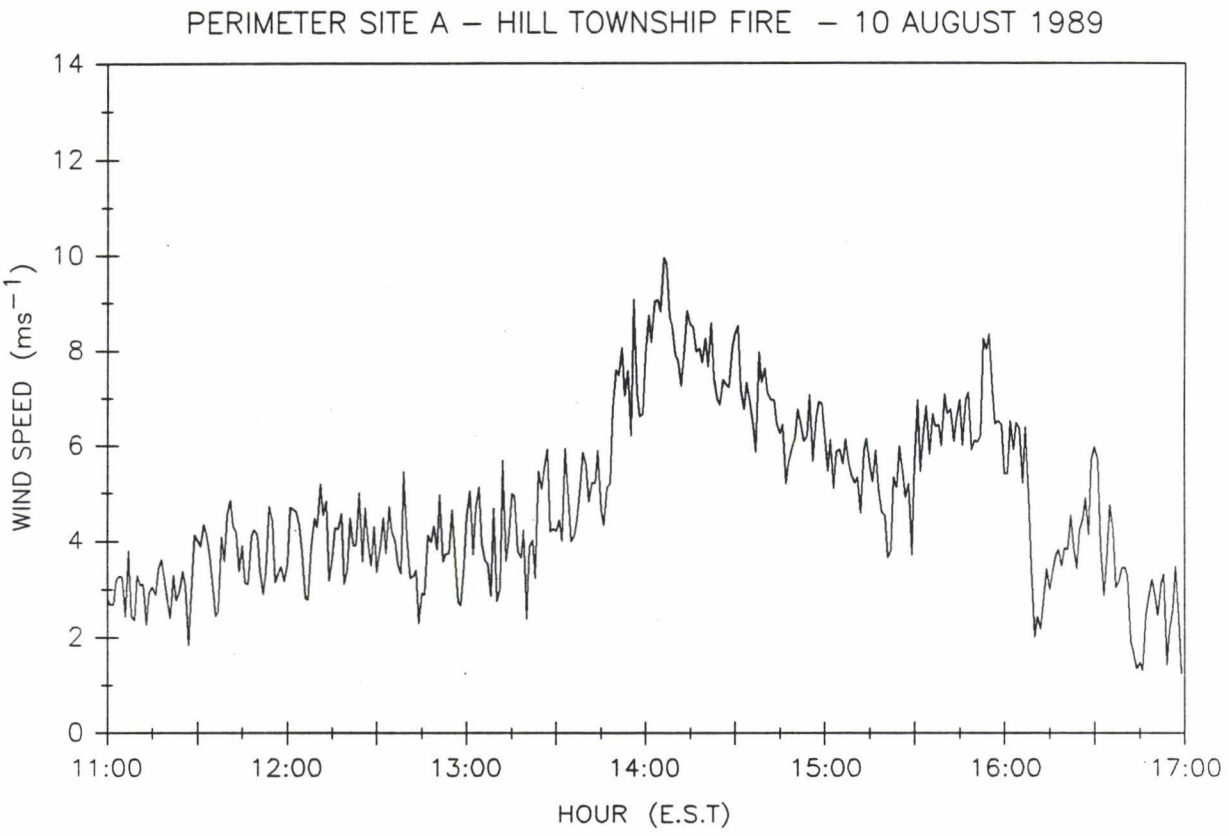
TO INTEGRATE THE IN-FIRE NEAR SURFACE (10M) WINDS WITH PERIMETER WIND DATA USING DATA BEING PROVIDED AS PART OF THE OVERALL PROJECT BY FORESTRY CANADA

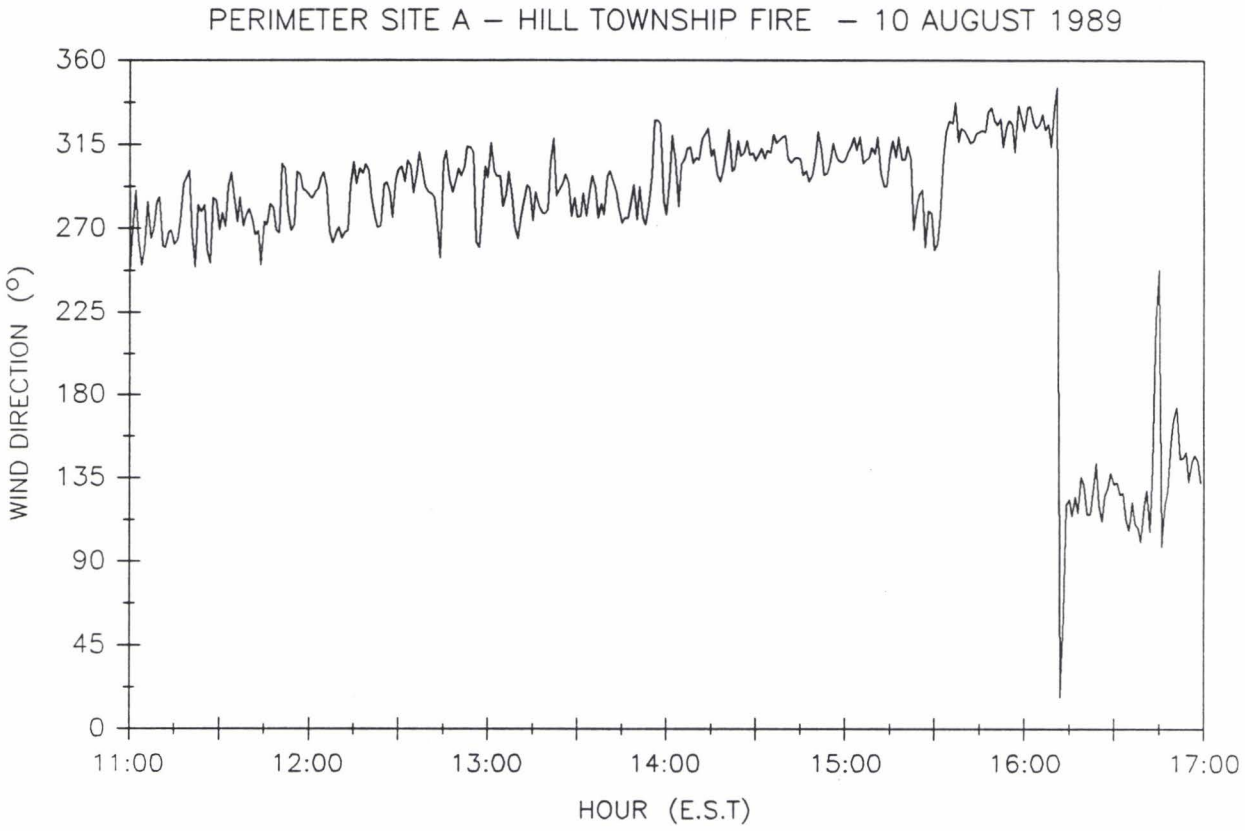
PROGRESS TO DATE:

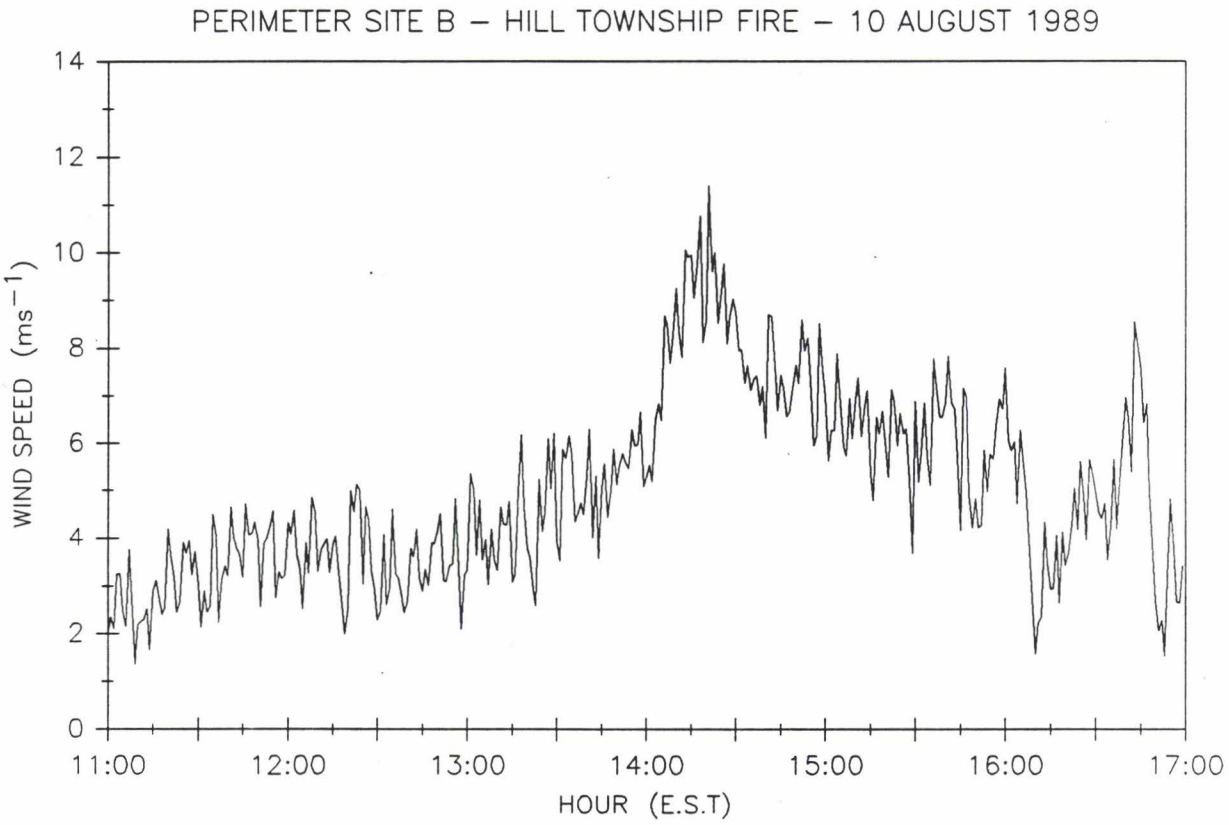
The perimeter wind data supplied by the Canadian Forest Service has been standardized to the rest of the in-fire horizontal data and test wind fields have been run on the Cray and here on campus. The perimeter wind data is summarized in graphical form on the following pages.

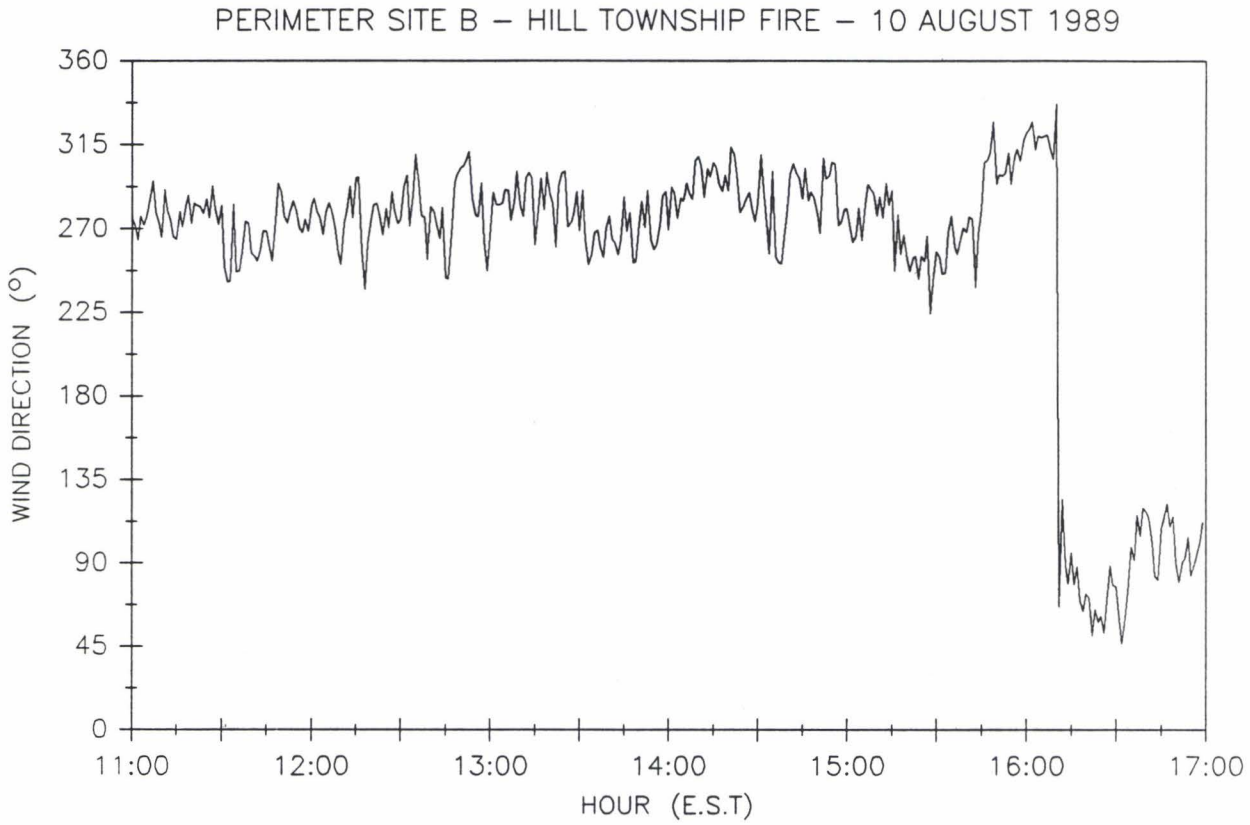
RELATIVE LOCATION OF IOWA EXPERIMENTAL TOWERS, HILL TOWNSHIP FIRE

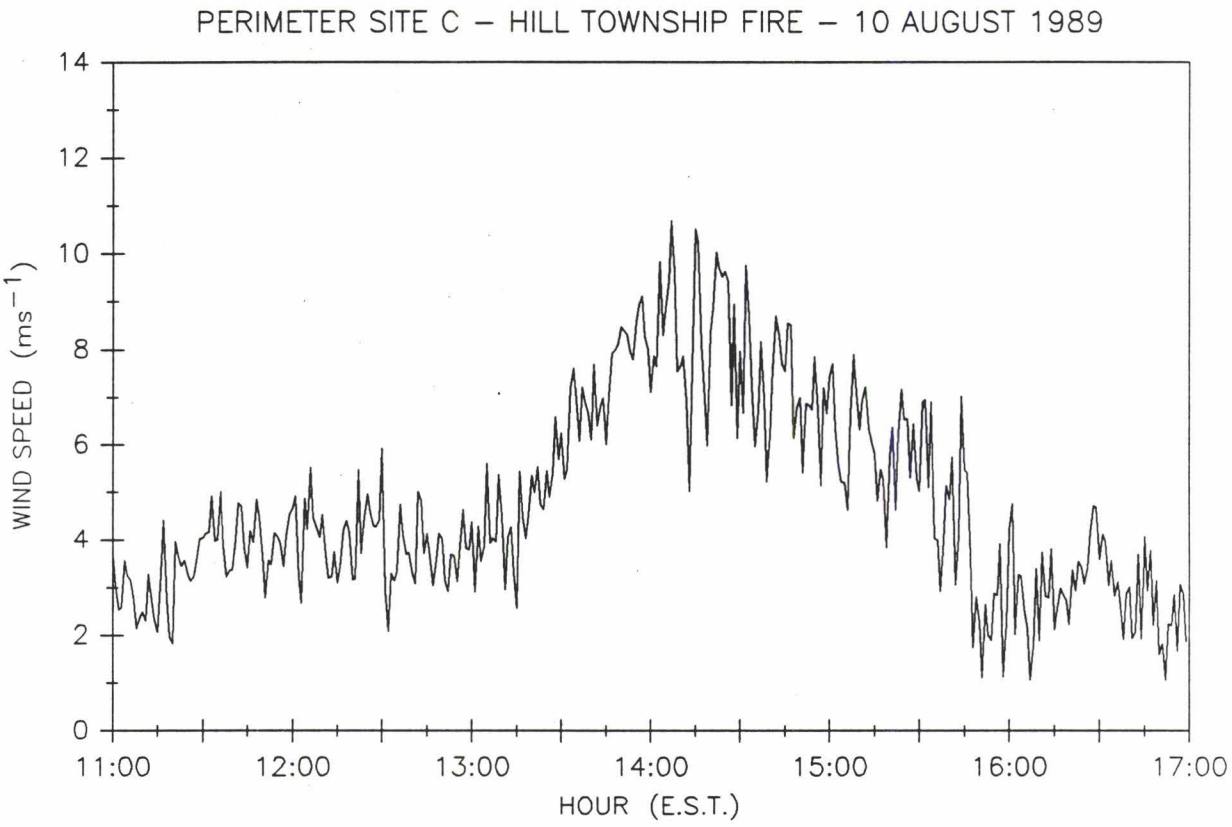


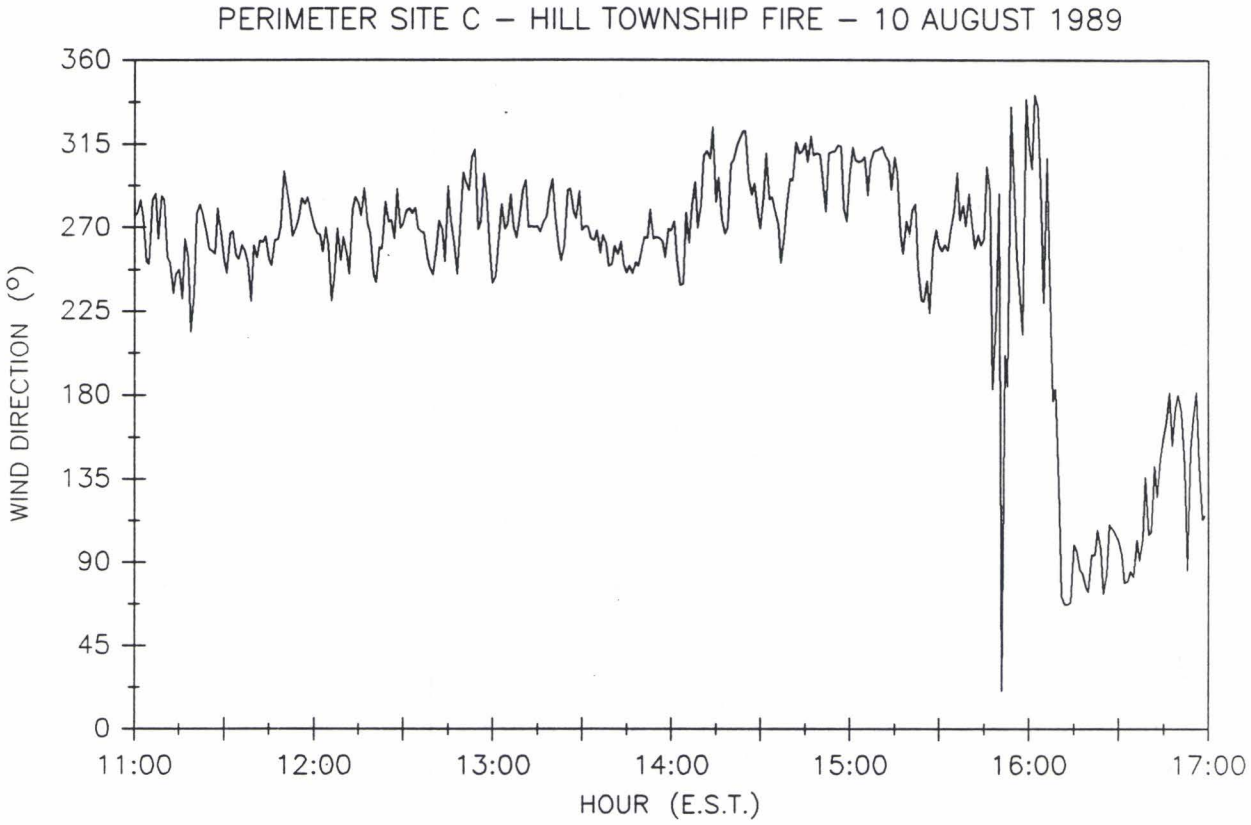

PERIMETER SITE A – HILL TOWNSHIP FIRE – 10 AUGUST 1989
WIND SPEED (ms⁻¹)
0
2
4
6
8
10
12
14
11:00
12:00
13:00
14:00
15:00
16:00
17:00
HOUR (E.S.T)

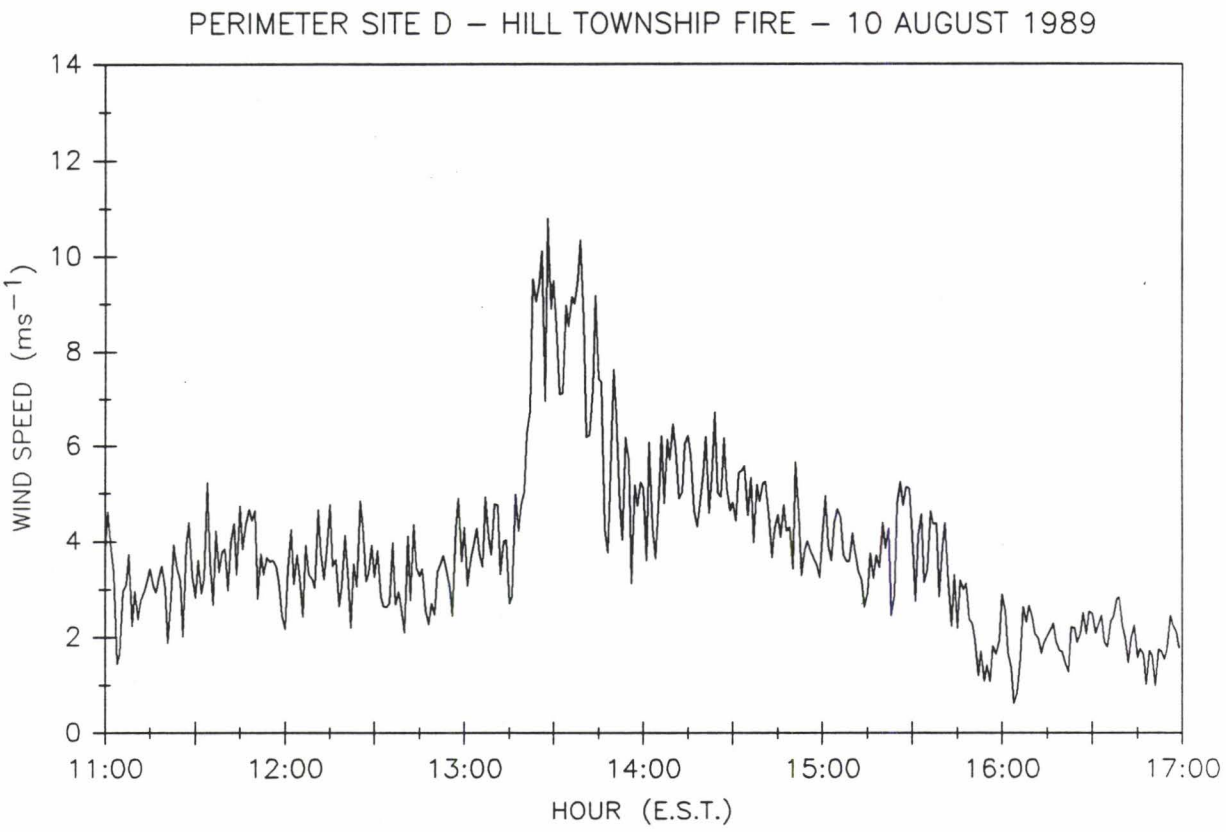

PERIMETER SITE A – HILL TOWNSHIP FIRE – 10 AUGUST 1989
WIND DIRECTION (°)
360
315
270
225
180
135
90
45
0
11:00
12:00
13:00
14:00
15:00
16:00
17:00
HOUR (E.S.T)

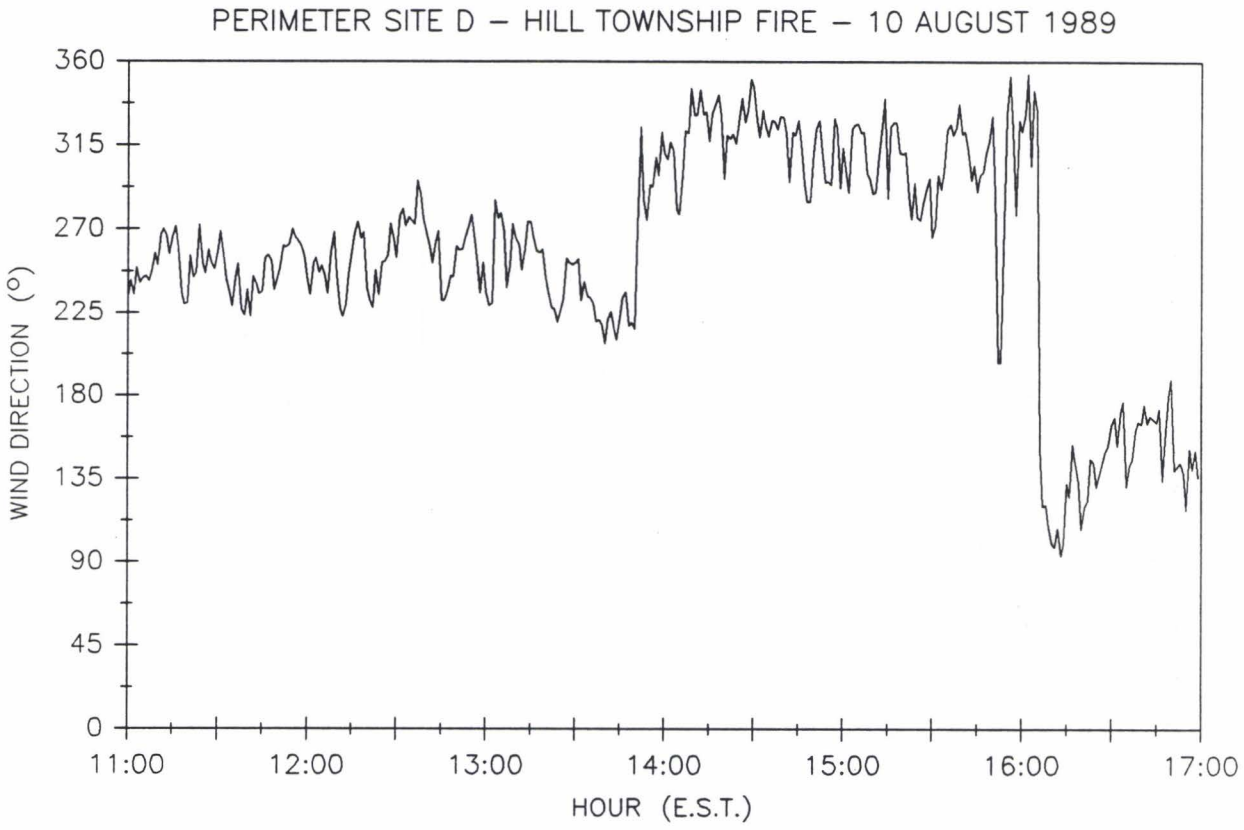

PERIMETER SITE B – HILL TOWNSHIP FIRE – 10 AUGUST 1989
WIND SPEED (ms^{-1})
0
2
4
6
8
10
12
14
11:00
12:00
13:00
14:00
15:00
16:00
17:00
HOUR (E.S.T)

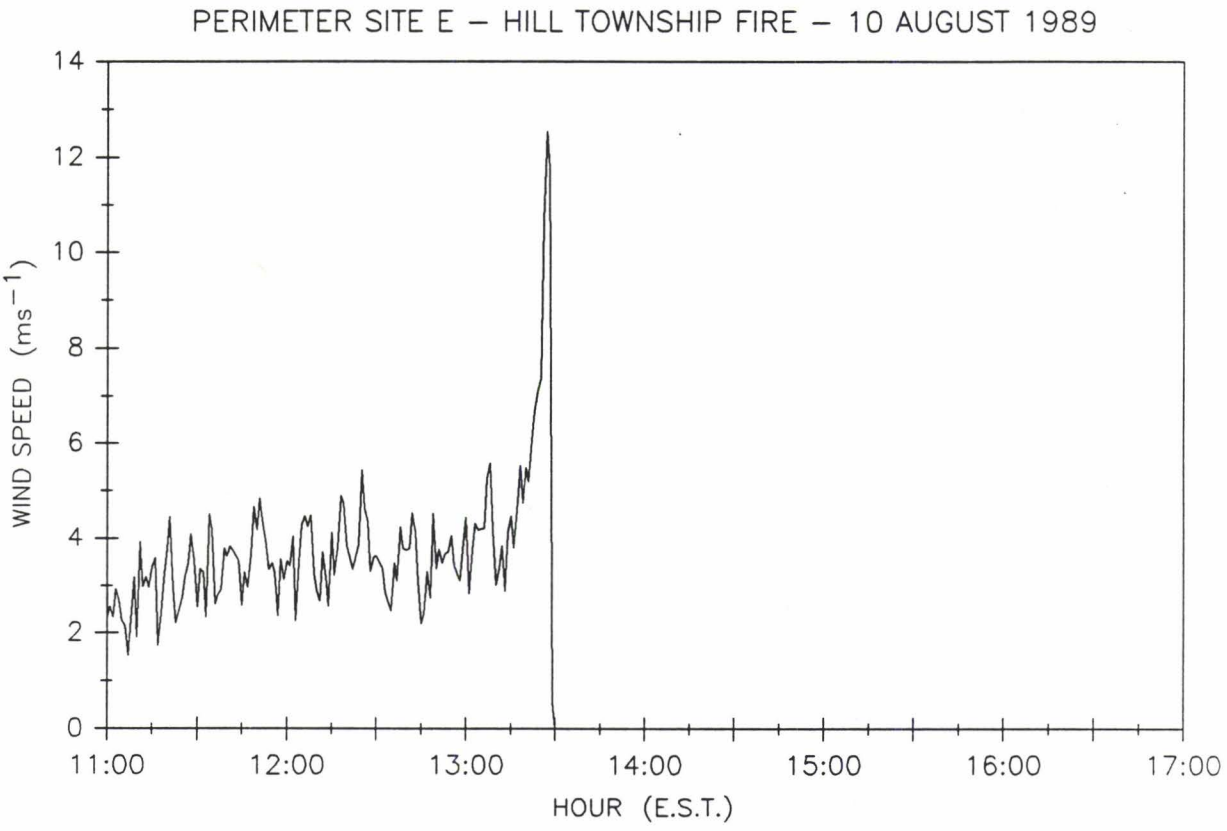

PERIMETER SITE B – HILL TOWNSHIP FIRE – 10 AUGUST 1989
360
315
270
225
180
135
90
45
0
WIND DIRECTION (°)
11:00
12:00
13:00
14:00
15:00
16:00
17:00
HOUR (E.S.T)

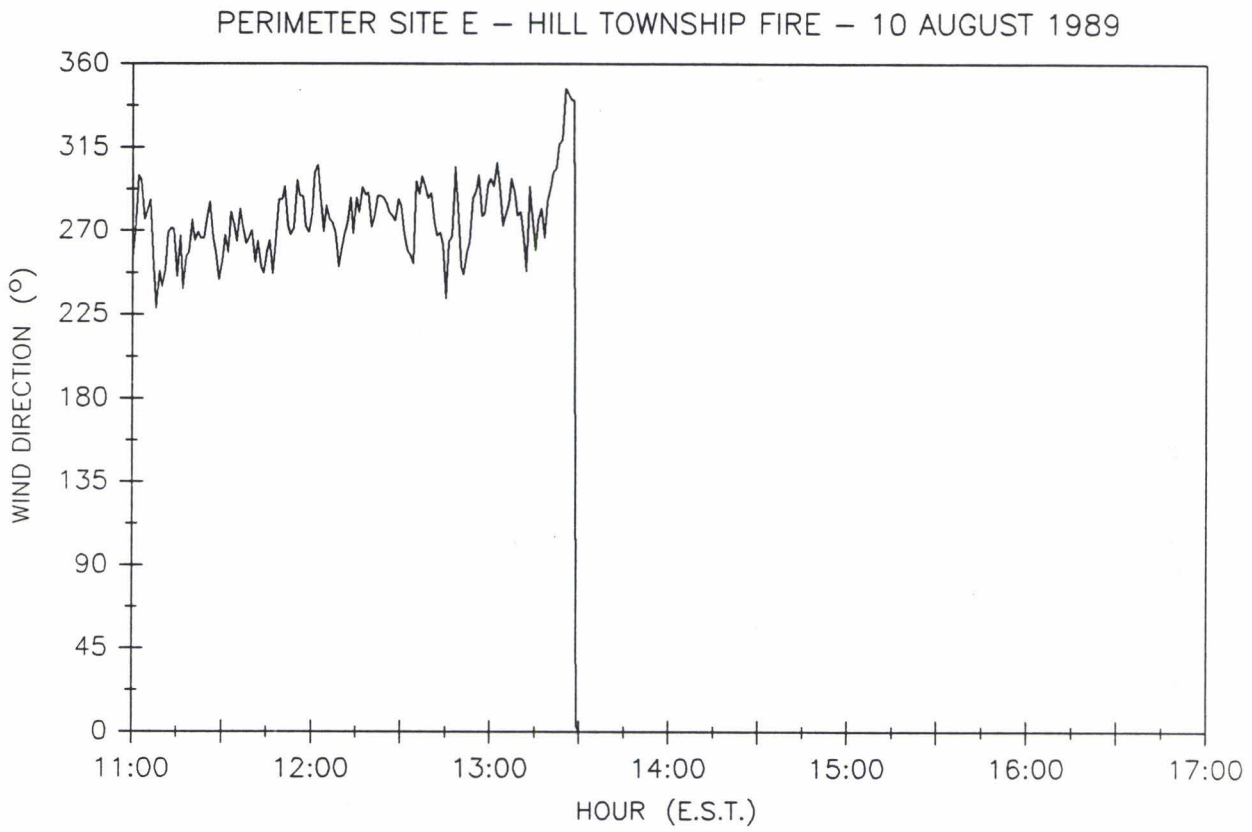

PERIMETER SITE C – HILL TOWNSHIP FIRE – 10 AUGUST 1989
WIND SPEED (ms^{-1})
0
2
4
6
8
10
12
14
11:00
12:00
13:00
14:00
15:00
16:00
17:00
HOUR (E.S.T.)

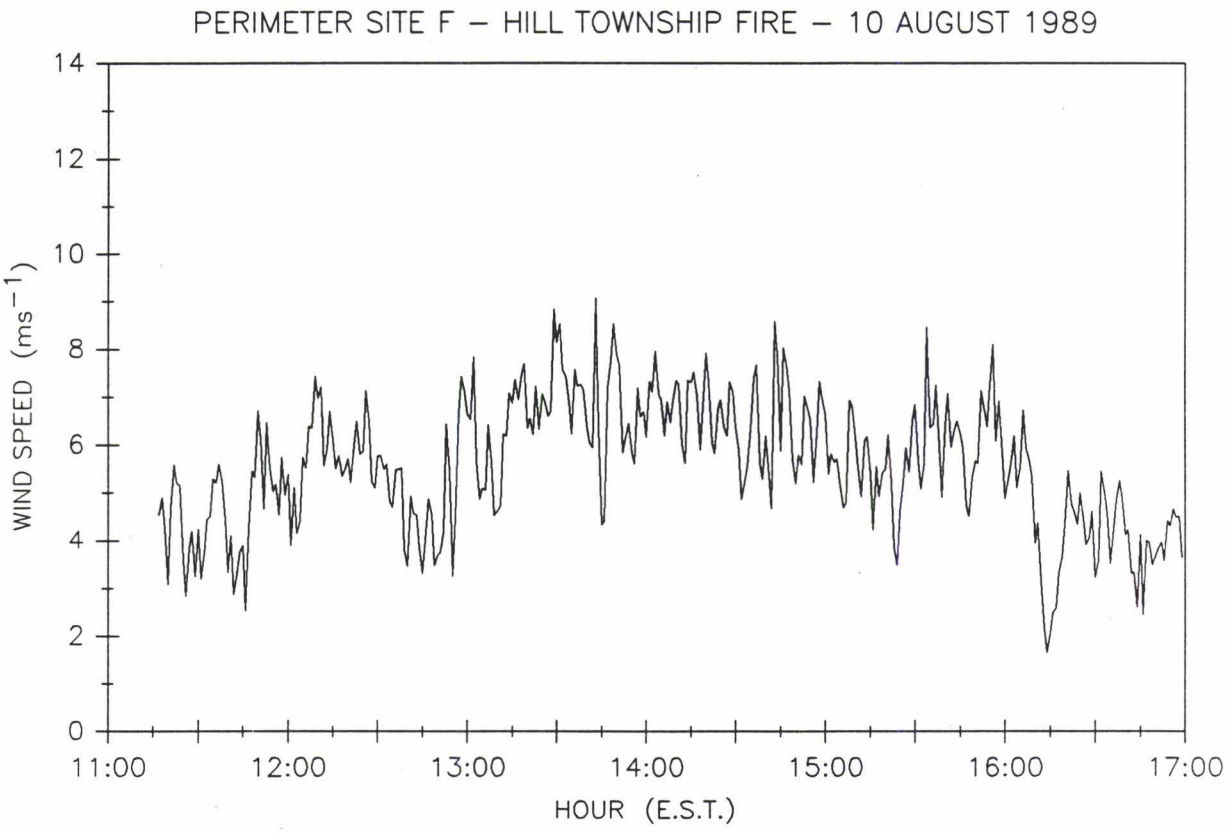

PERIMETER SITE C – HILL TOWNSHIP FIRE – 10 AUGUST 1989
WIND DIRECTION (°)
360
315
270
225
180
135
90
45
0
11:00
12:00
13:00
14:00
15:00
16:00
17:00
HOUR (E.S.T.)

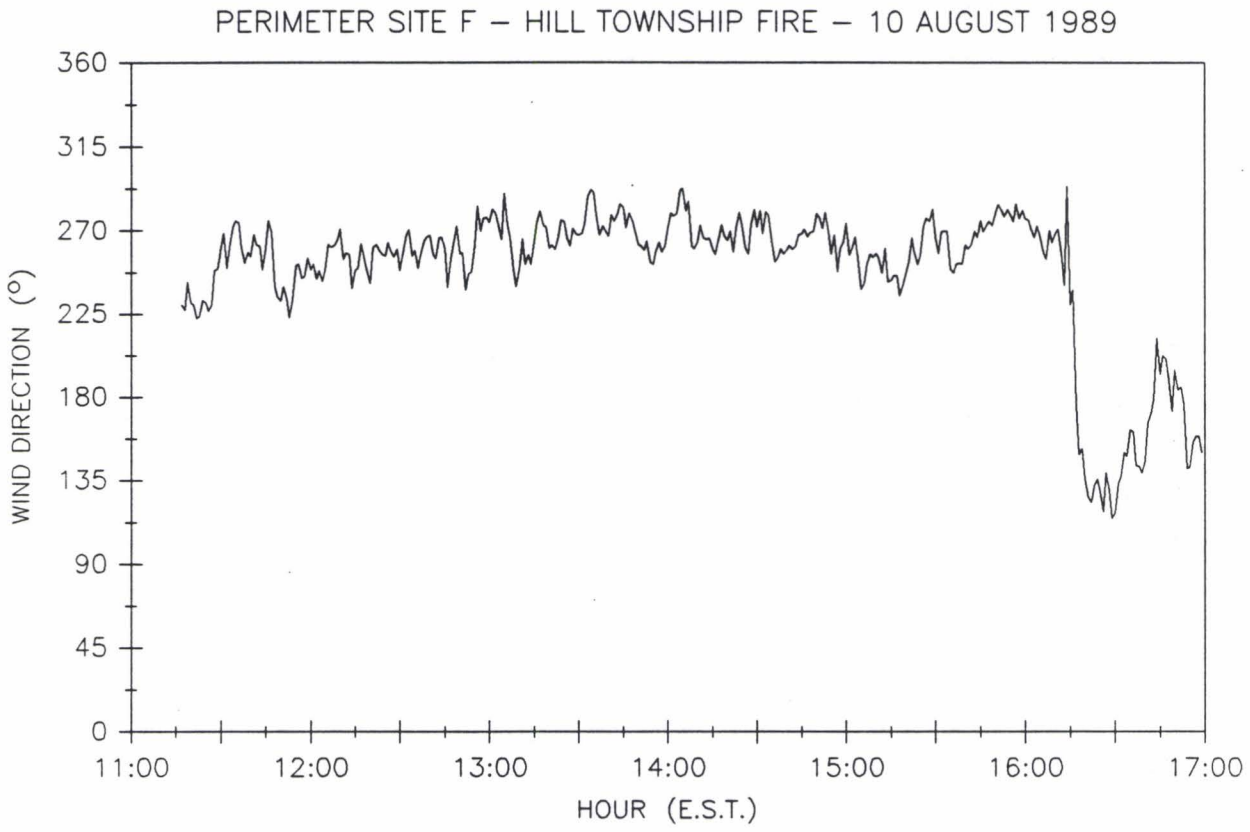

PERIMETER SITE D – HILL TOWNSHIP FIRE – 10 AUGUST 1989
WIND SPEED (ms^{-1})
0
2
4
6
8
10
12
14
11:00
12:00
13:00
14:00
15:00
16:00
17:00
HOUR (E.S.T.)

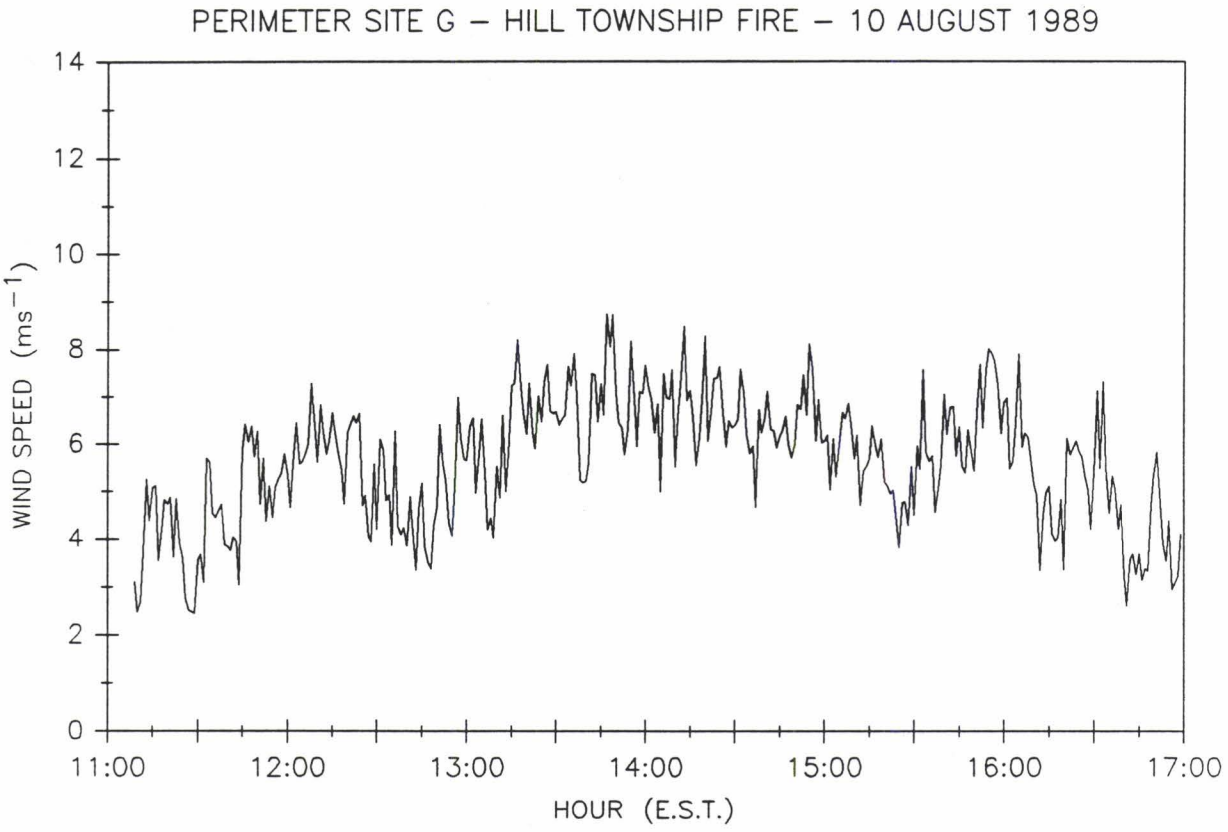

PERIMETER SITE D – HILL TOWNSHIP FIRE – 10 AUGUST 1989
WIND DIRECTION (°)
360
315
270
225
180
135
90
45
0
11:00
12:00
13:00
14:00
15:00
16:00
17:00
HOUR (E.S.T.)

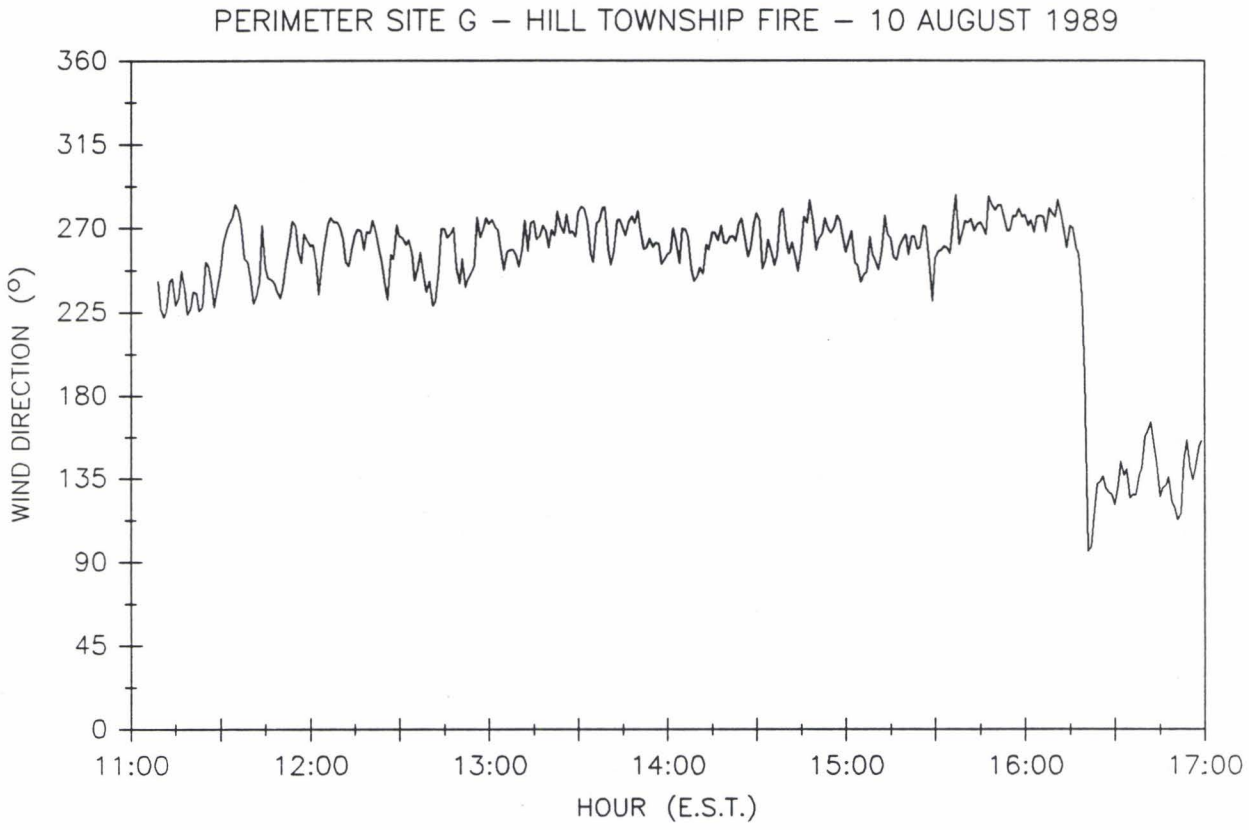

PERIMETER SITE E – HILL TOWNSHIP FIRE – 10 AUGUST 1989
WIND SPEED (ms^{-1})
0
2
4
6
8
10
12
14
11:00
12:00
13:00
14:00
15:00
16:00
17:00
HOUR (E.S.T.)


PERIMETER SITE E – HILL TOWNSHIP FIRE – 10 AUGUST 1989
360
315
270
225
180
135
90
45
0
WIND DIRECTION (°)
11:00
12:00
13:00
14:00
15:00
16:00
17:00
HOUR (E.S.T.)


PERIMETER SITE F – HILL TOWNSHIP FIRE – 10 AUGUST 1989
WIND SPEED (ms^{-1})
0
2
4
6
8
10
12
14
11:00
12:00
13:00
14:00
15:00
16:00
17:00
HOUR (E.S.T.)


PERIMETER SITE F – HILL TOWNSHIP FIRE – 10 AUGUST 1989
WIND DIRECTION (°)
360
315
270
225
180
135
90
45
0
11:00
12:00
13:00
14:00
15:00
16:00
17:00
HOUR (E.S.T.)


PERIMETER SITE G – HILL TOWNSHIP FIRE – 10 AUGUST 1989
WIND SPEED (ms^{-1})
0
2
4
6
8
10
12
14
11:00
12:00
13:00
14:00
15:00
16:00
17:00
HOUR (E.S.T.)


PERIMETER SITE G – HILL TOWNSHIP FIRE – 10 AUGUST 1989
WIND DIRECTION (°)
360
315
270
225
180
135
90
45
0
11:00
12:00
13:00
14:00
15:00
16:00
17:00
HOUR (E.S.T.)

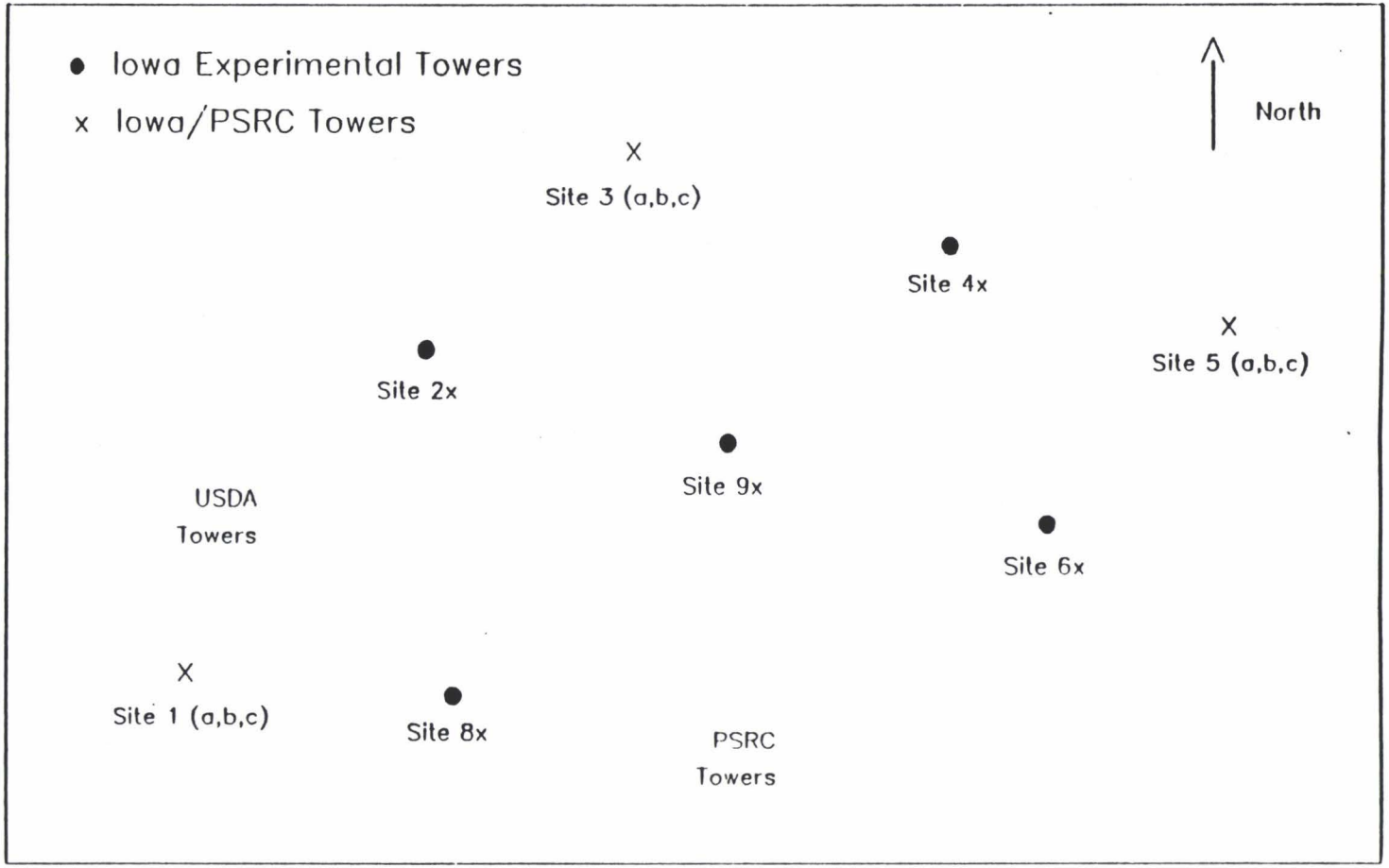
GOAL 4 (OBJECTIVE H)

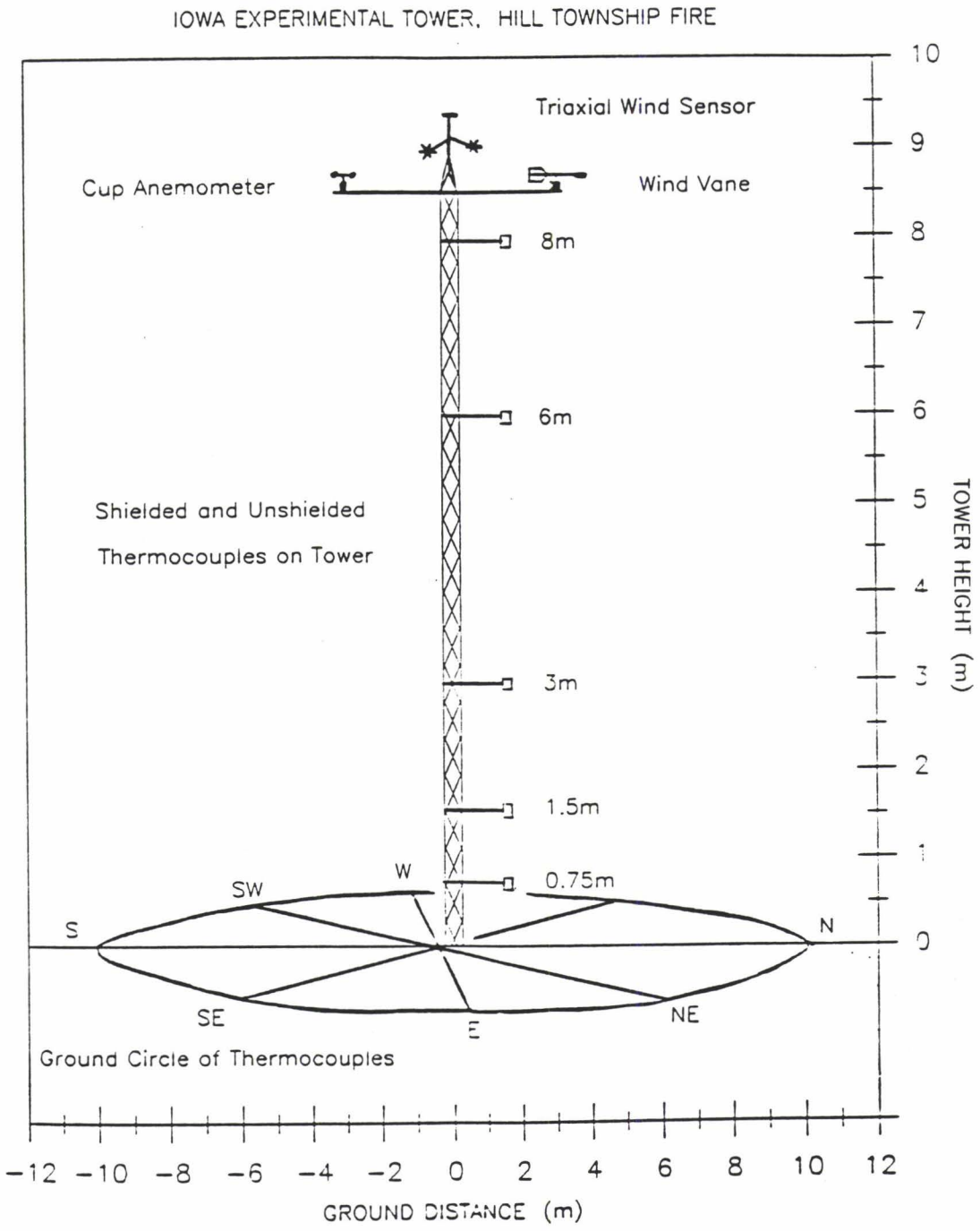
TO OBTAIN AND ANALYZE NEAR TOWER SURFACE AND LOCALIZED FIRE SPREAD RATE DATA ON A 10M RADIUS (20M DIAMETER) 8 POINT GROUND SURFACE THERMOCOUPLE ARRAY DEPLOYED AROUND THE FIRE

PROGRESS TO DATE:

The data has been reduced and analyzed and localized spread rates have been determined. This will be integrated with other related spread rate date in the final report. Locations and graphical presentation of the data follows.

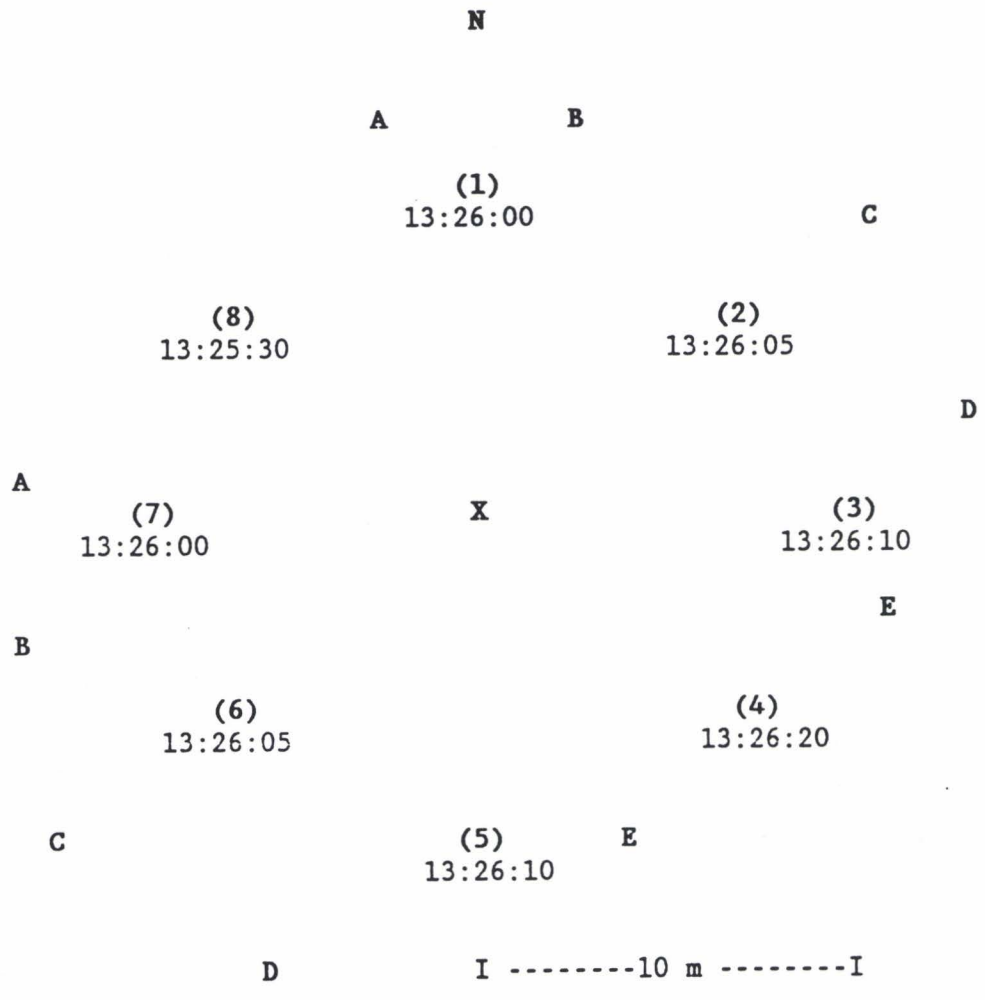
RELATIVE LOCATION OF IOWA EXPERIMENTAL TOWERS, HILL TOWNSHIP FIRE

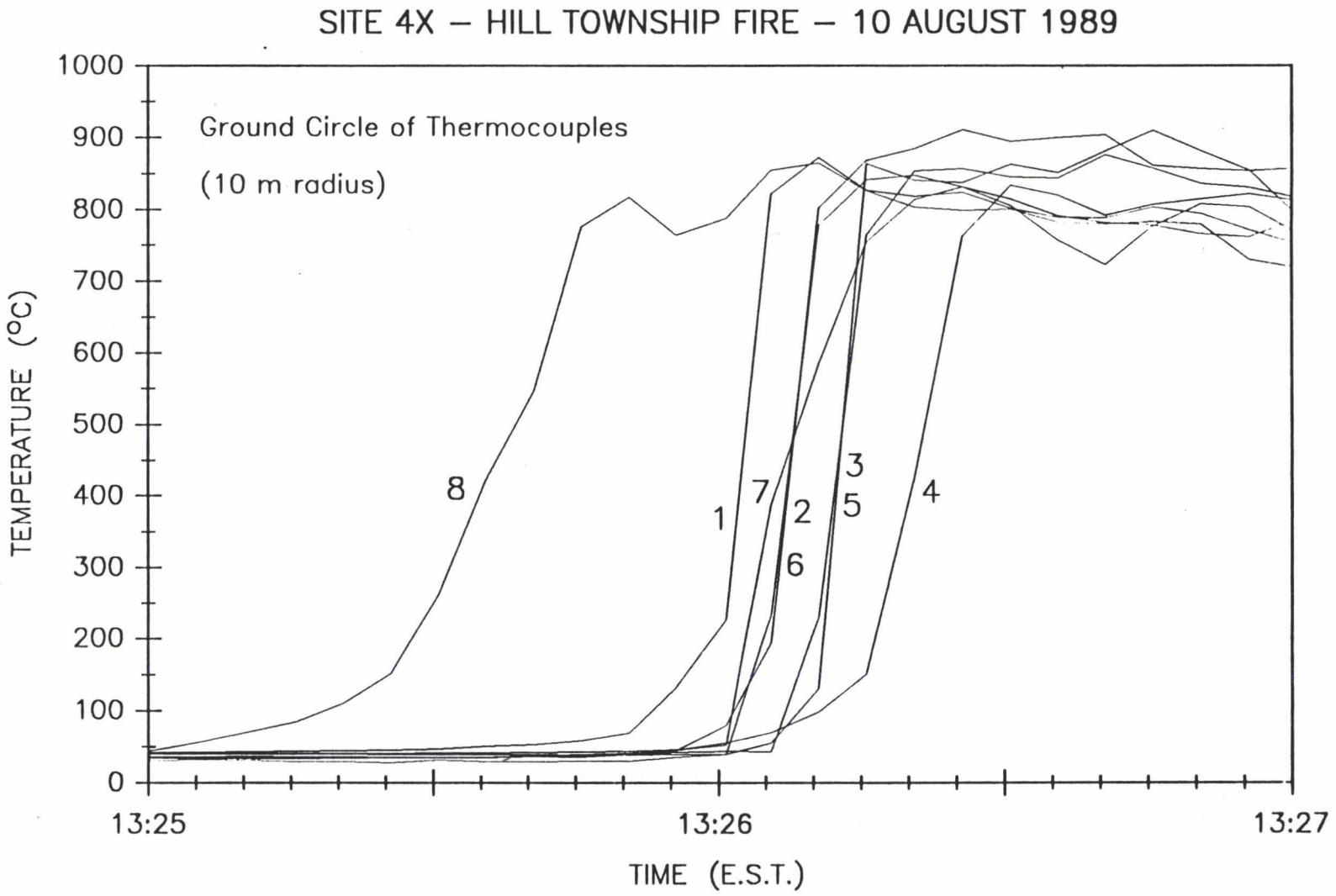


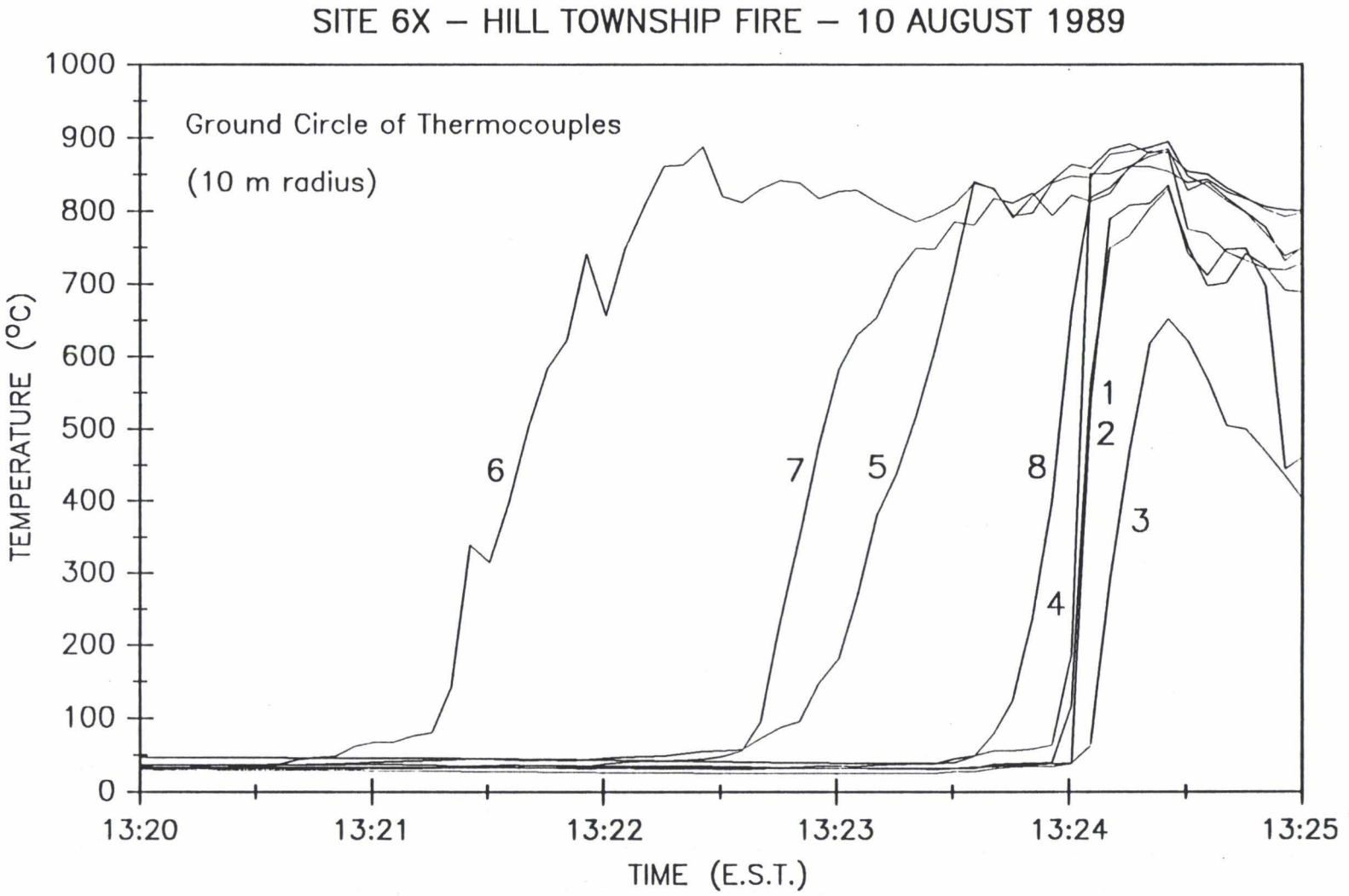

IOWA EXPERIMENTAL TOWER, HILL TOWNSHIP FIRE
Triaxial Wind Sensor
Cup Anemometer
Wind Vane
8m
6m
Shielded and Unshielded
Thermocouples on Tower
3m
1.5m
0.75m
W
SW
S
N
SE
E
NE
Ground Circle of Thermocouples
10
9
8
7
6
5
4
3
2
1
0
TOWER HEIGHT (m)
−12 −10 −8 −6 −4 −2 0 2 4 6 8 10 12
GROUND DISTANCE (m)

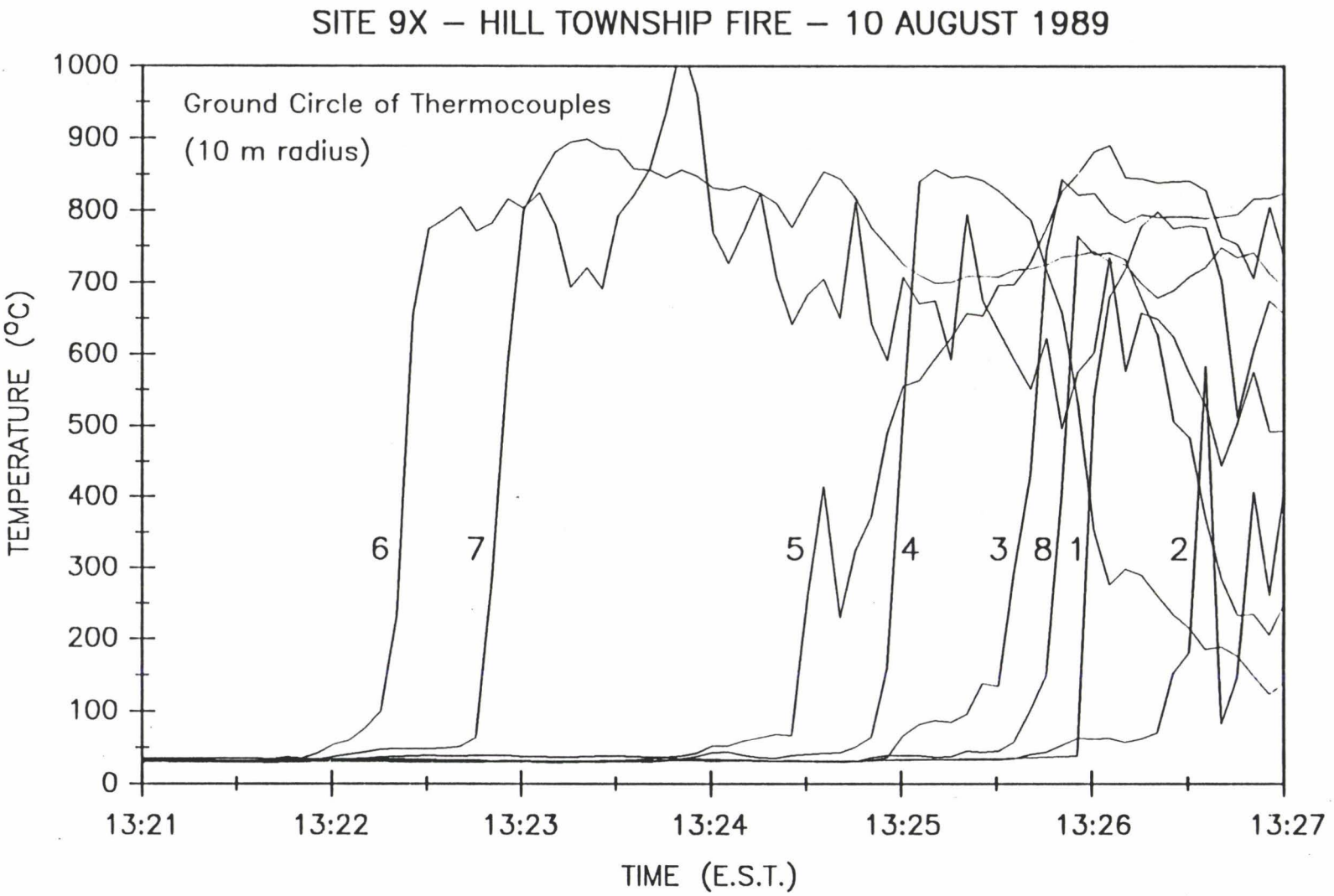
SITE 4 X

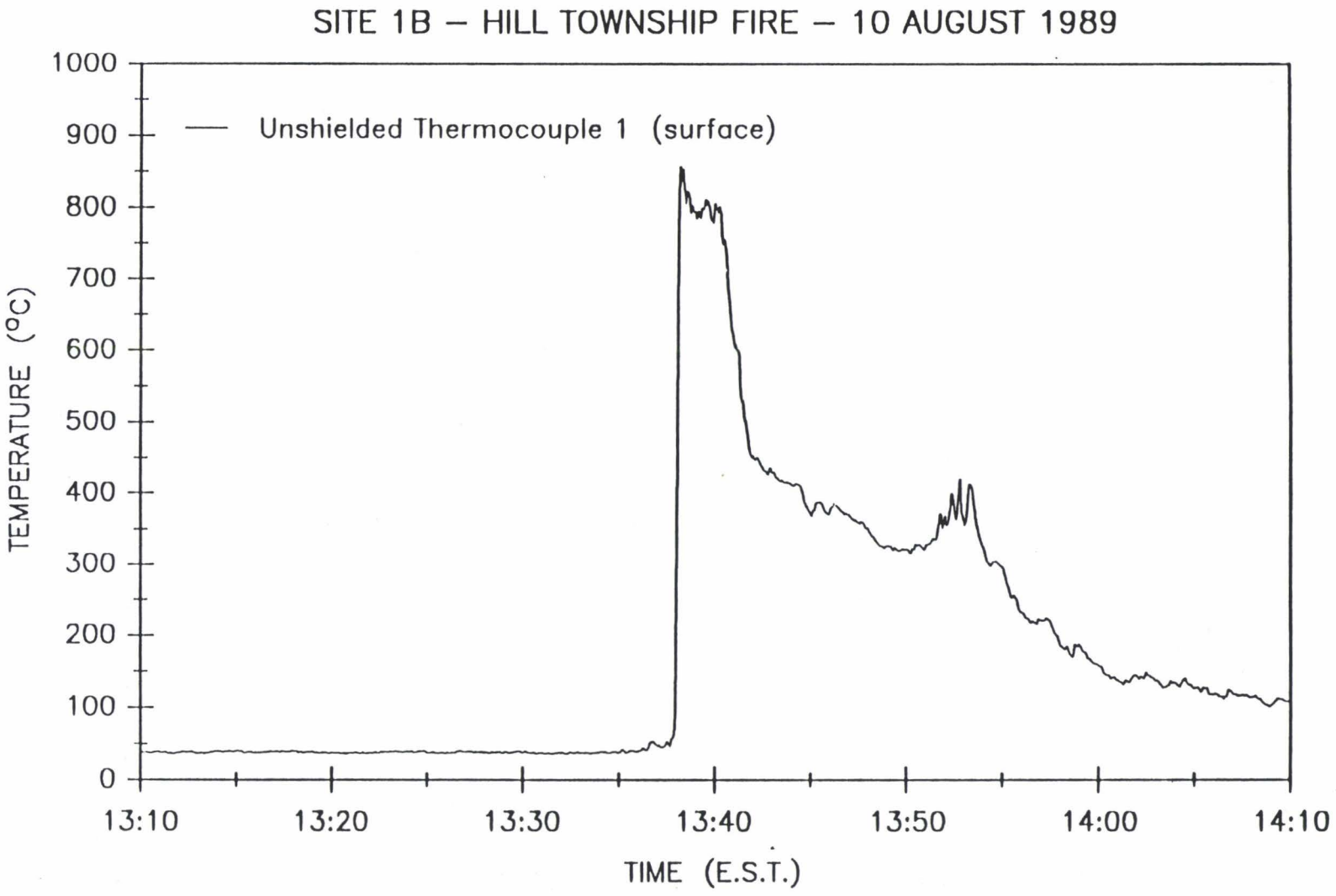
GROUND ARRAY FIRE SPREAD RATES

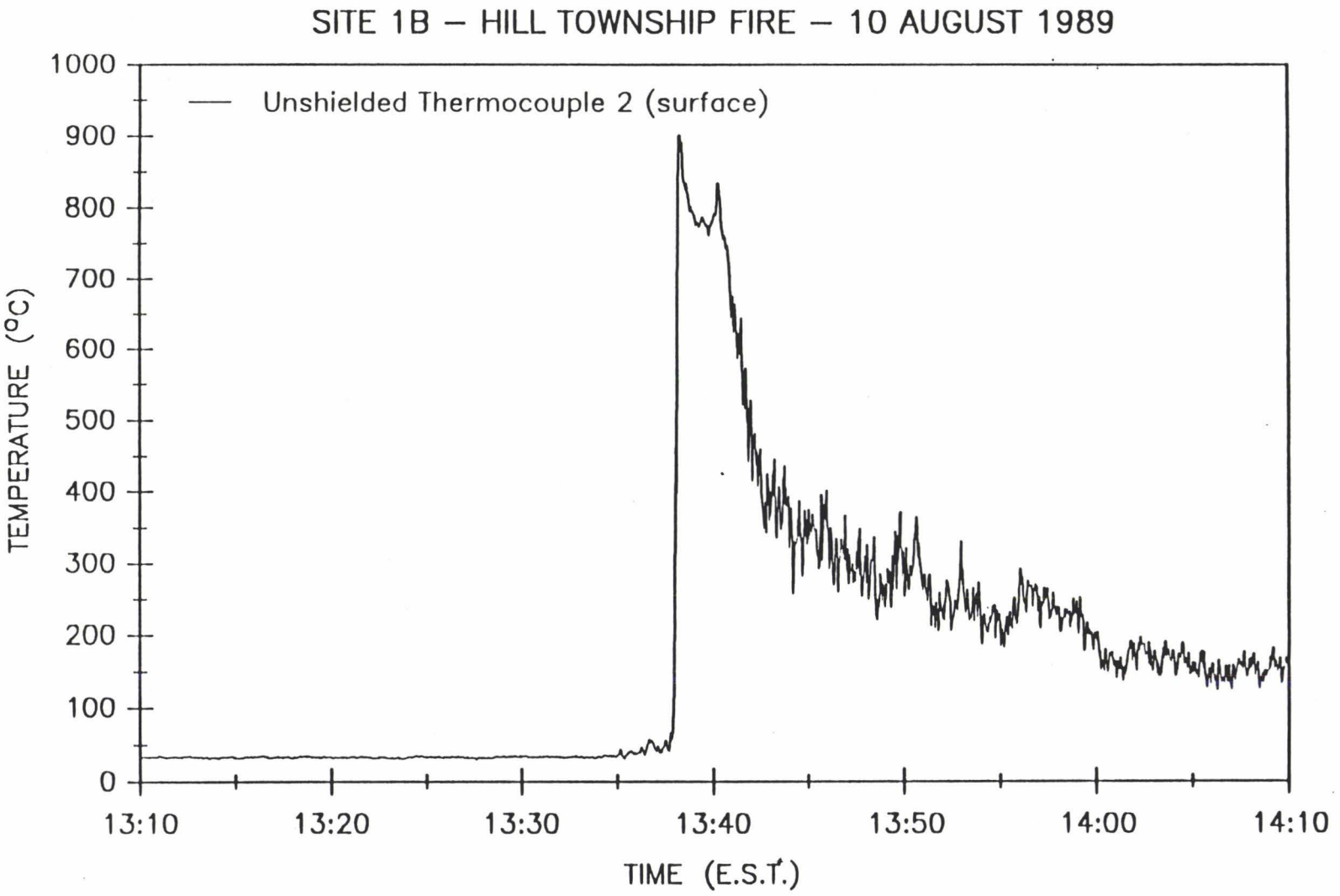


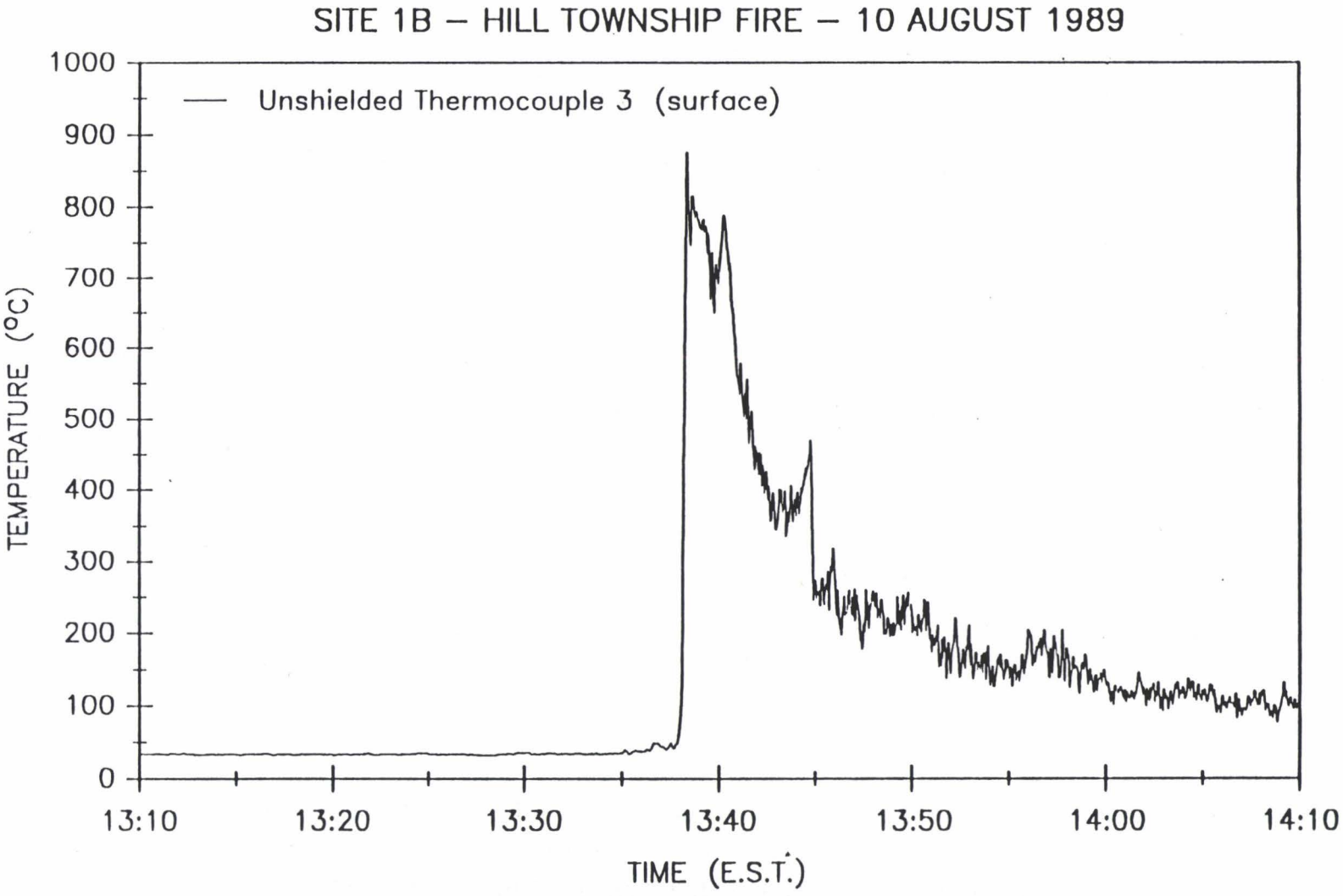

SITE 4X – HILL TOWNSHIP FIRE – 10 AUGUST 1989
Ground Circle of Thermocouples
(10 m radius)
TEMPERATURE (°C)
1000
900
800
700
600
500
400
300
200
100
0
8
1
7
2
6
3
5
4
13:25
13:26
13:27
TIME (E.S.T.)

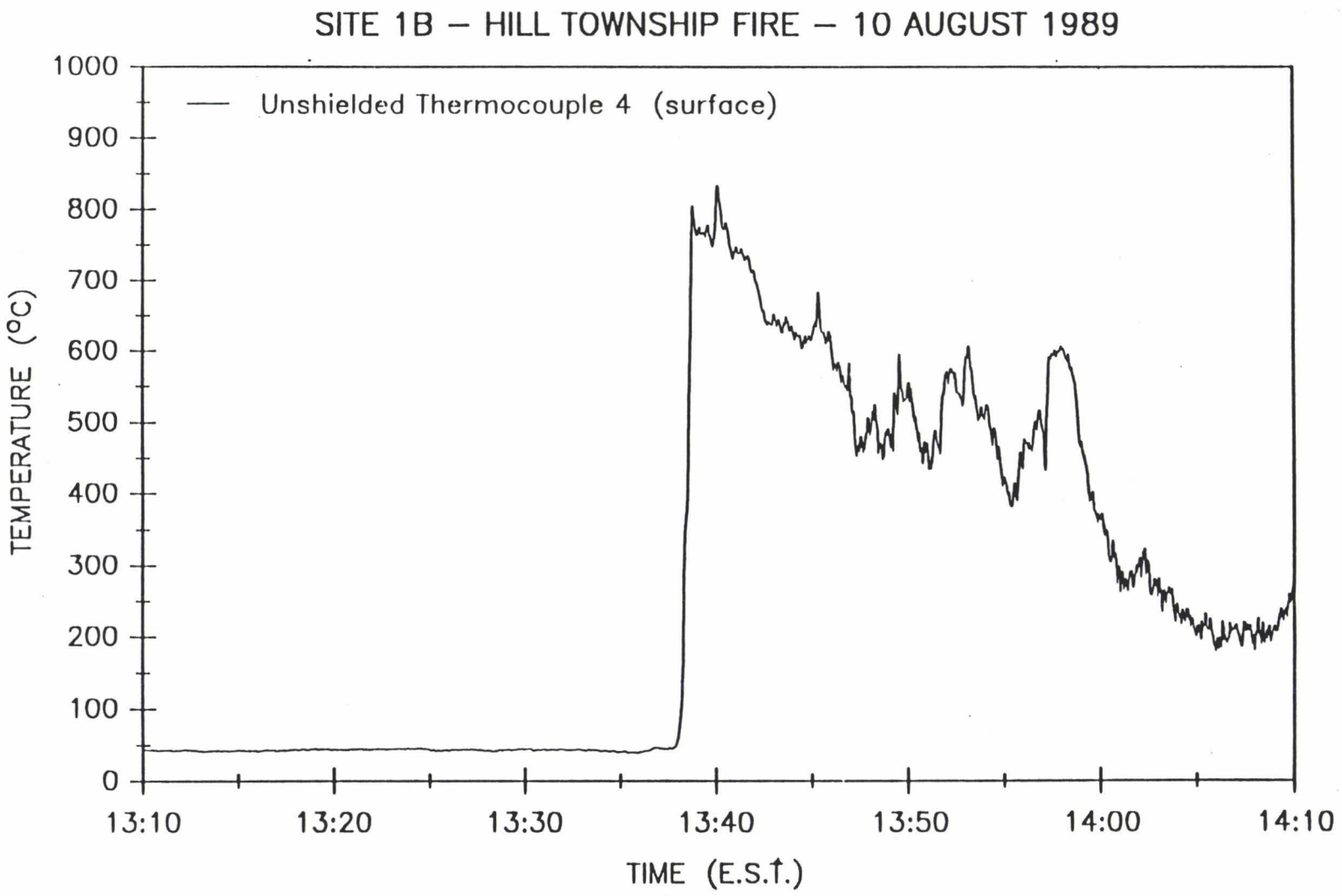

SITE 6X – HILL TOWNSHIP FIRE – 10 AUGUST 1989
Ground Circle of Thermocouples
(10 m radius)
TEMPERATURE (°C)
1000
900
800
700
600
500
400
300
200
100
0
13:20
13:21
13:22
13:23
13:24
13:25
TIME (E.S.T.)
6
7
5
8
1
2
3
4

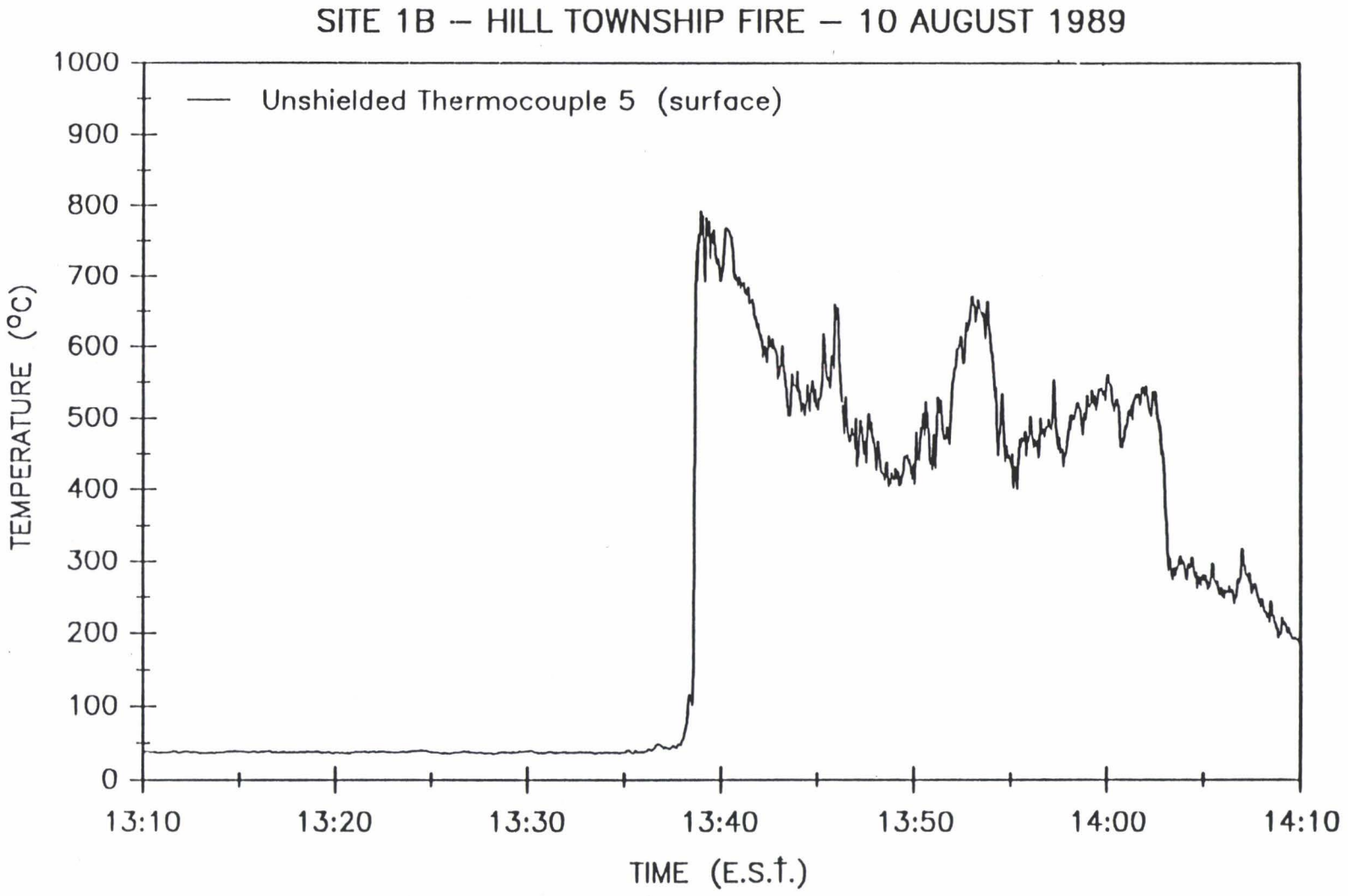

SITE 9X – HILL TOWNSHIP FIRE – 10 AUGUST 1989
Ground Circle of Thermocouples
(10 m radius)
TEMPERATURE (°C)
1000
900
800
700
600
500
400
300
200
100
0
6
7
5
4
3
8
1
2
13:21
13:22
13:23
13:24
13:25
13:26
13:27
TIME (E.S.T.)

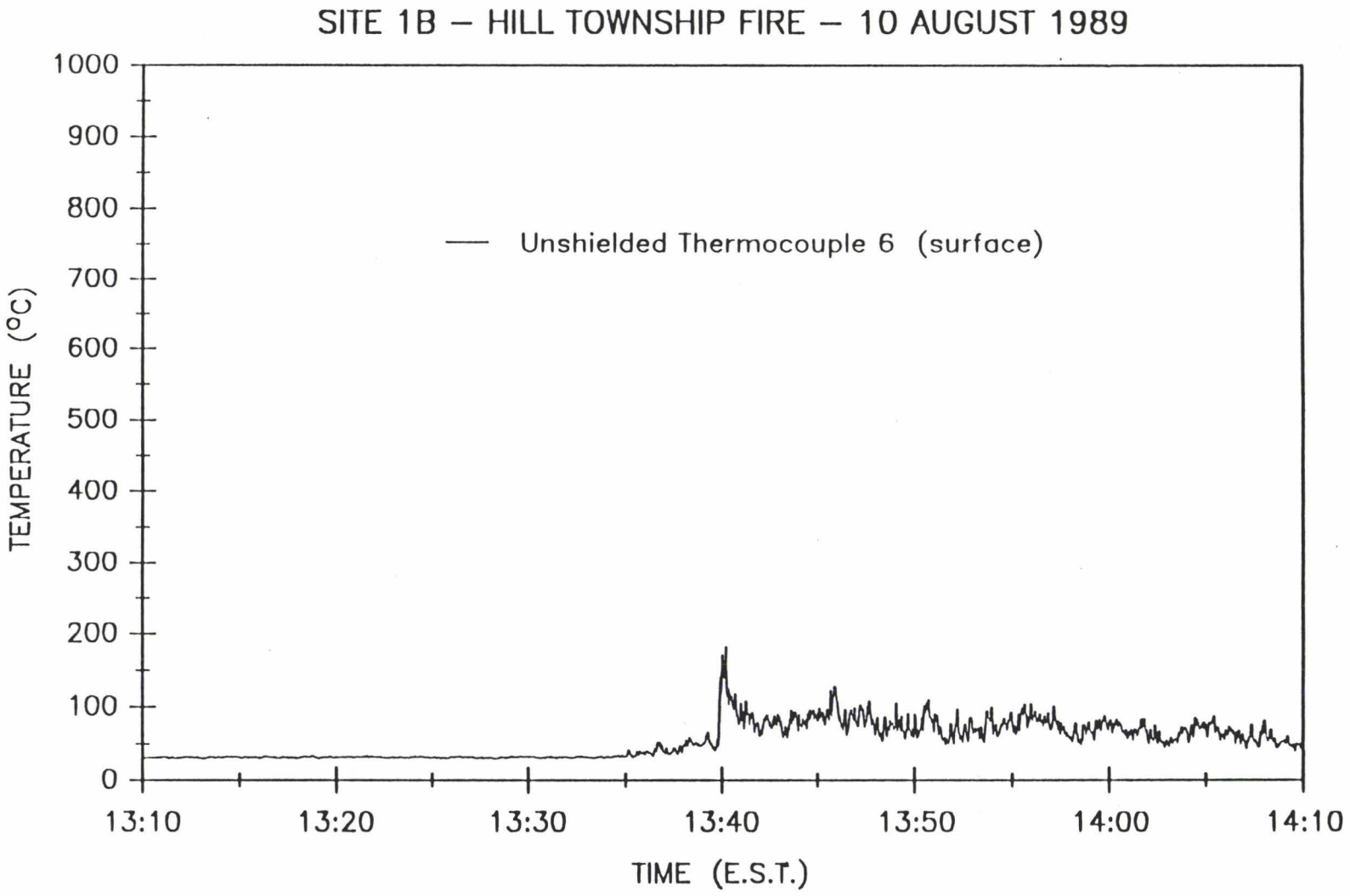

SITE 1B – HILL TOWNSHIP FIRE – 10 AUGUST 1989
Unshielded Thermocouple 1 (surface)
TEMPERATURE (°C)
1000
900
800
700
600
500
400
300
200
100
0
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)

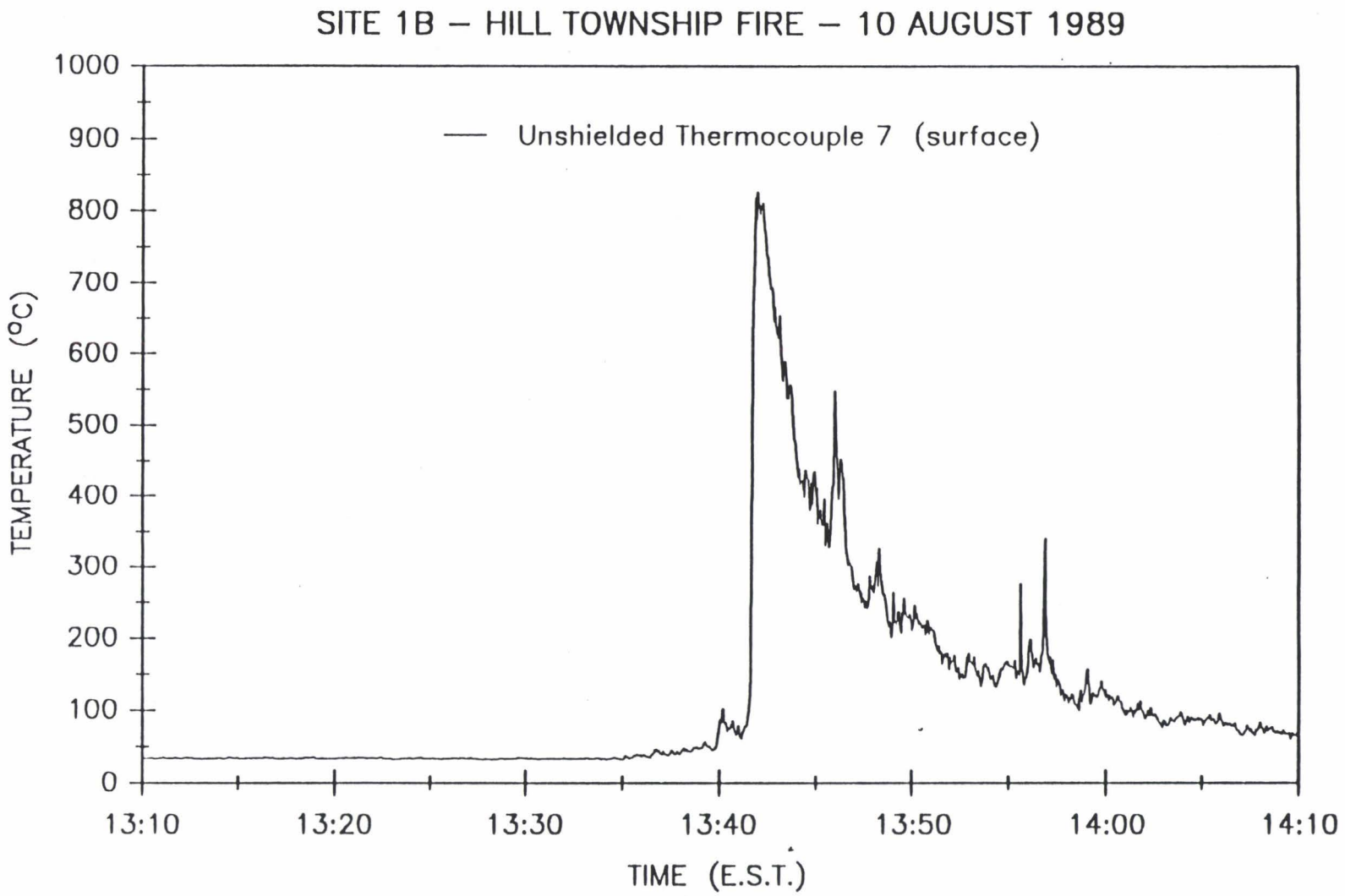

SITE 1B – HILL TOWNSHIP FIRE – 10 AUGUST 1989
Unshielded Thermocouple 2 (surface)
TEMPERATURE (°C)
1000
900
800
700
600
500
400
300
200
100
0
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)

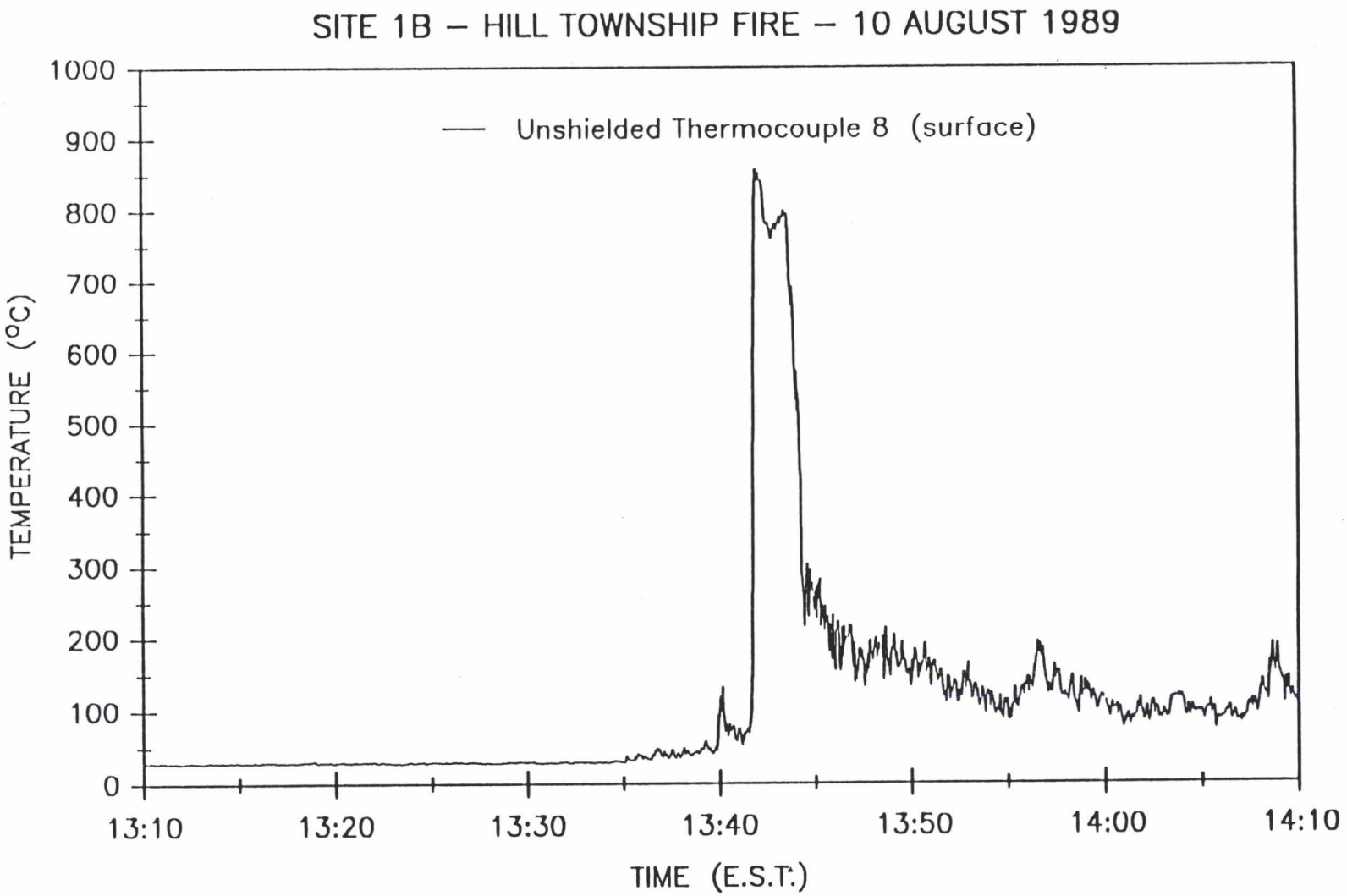

SITE 1B – HILL TOWNSHIP FIRE – 10 AUGUST 1989
Unshielded Thermocouple 3 (surface)
TEMPERATURE (°C)
1000
900
800
700
600
500
400
300
200
100
0
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)

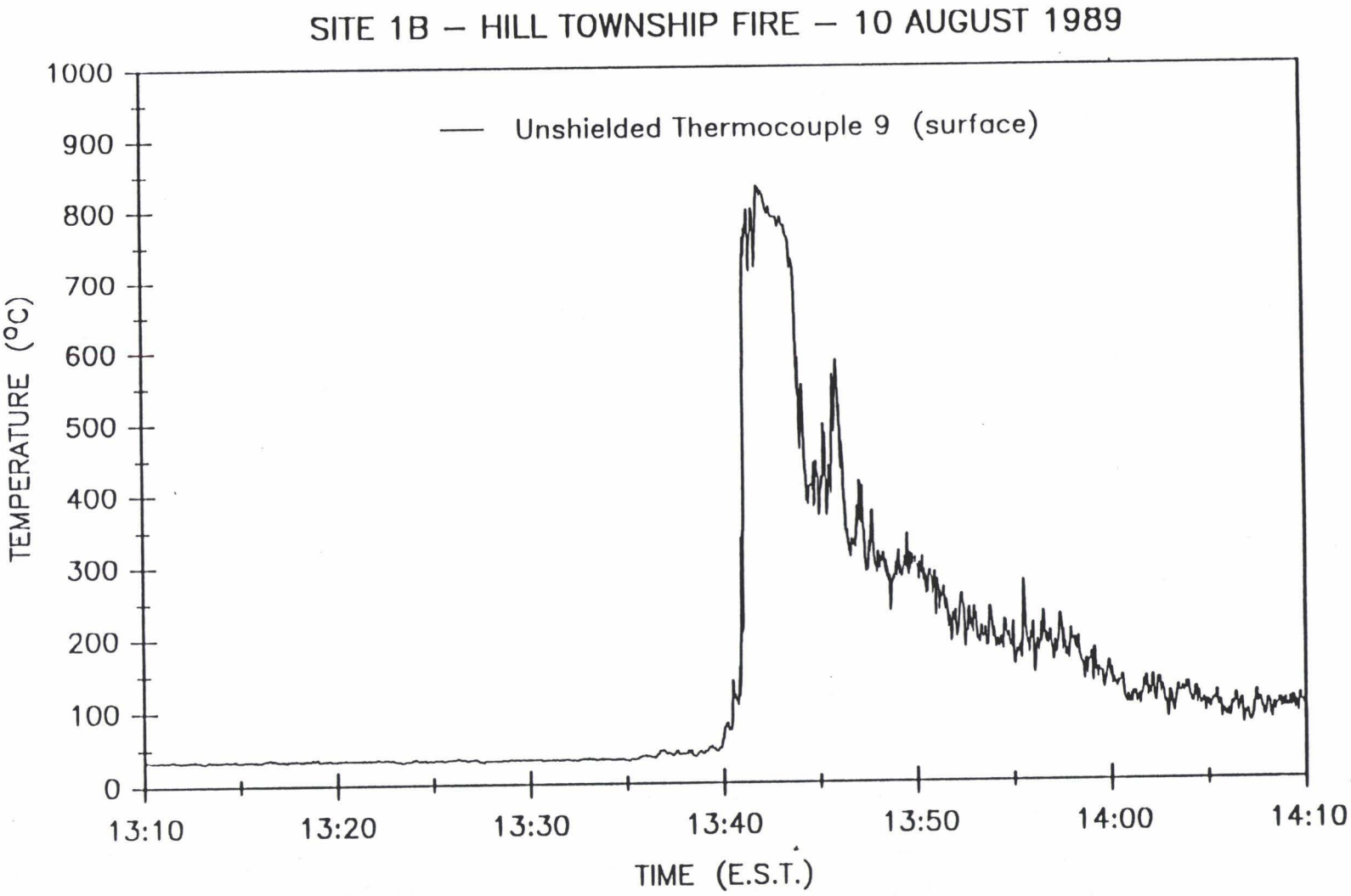

SITE 1B – HILL TOWNSHIP FIRE – 10 AUGUST 1989
Unshielded Thermocouple 4 (surface)
TEMPERATURE (°C)
1000
900
800
700
600
500
400
300
200
100
0
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)

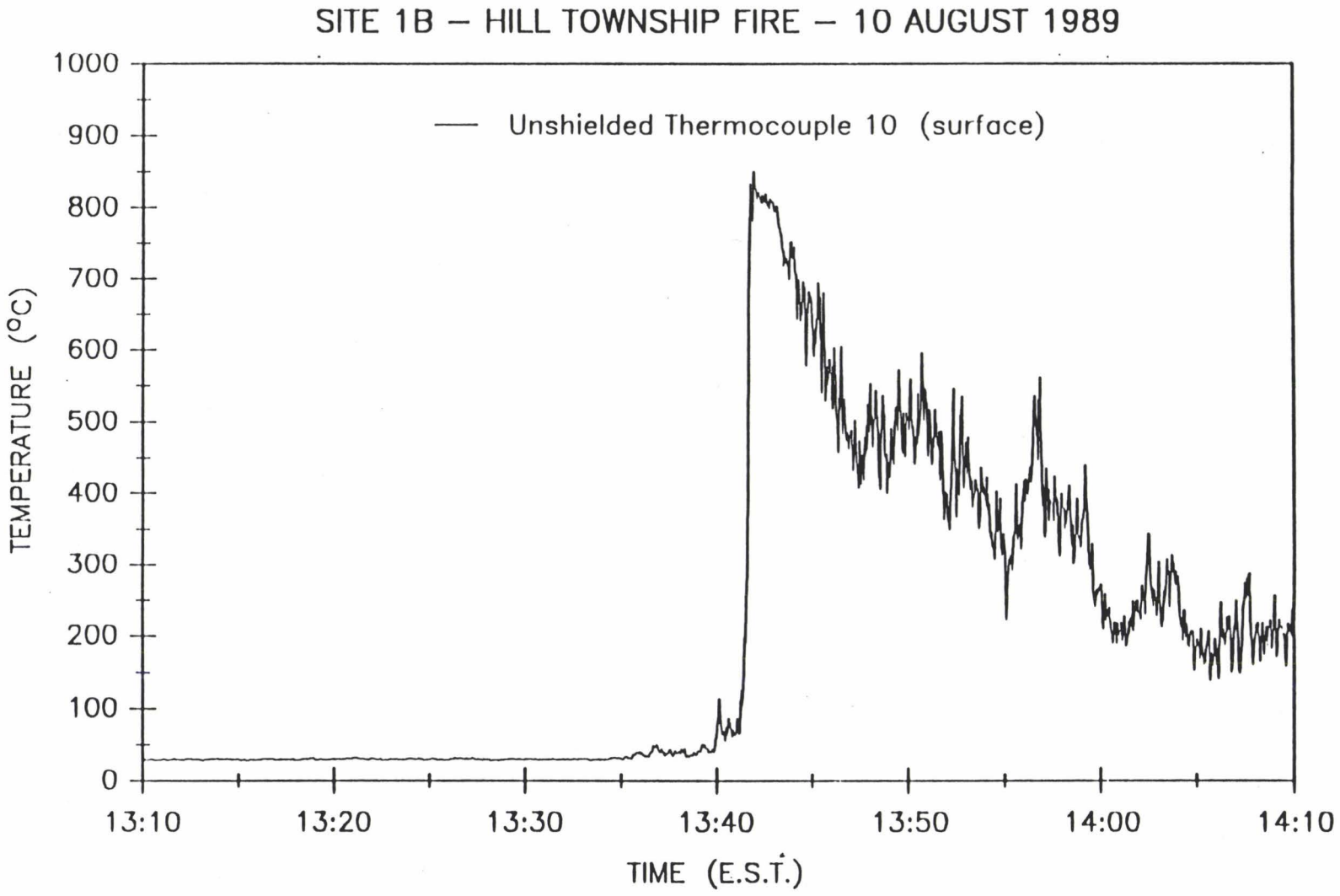

SITE 1B – HILL TOWNSHIP FIRE – 10 AUGUST 1989
Unshielded Thermocouple 5 (surface)
TEMPERATURE (°C)
1000
900
800
700
600
500
400
300
200
100
0
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)

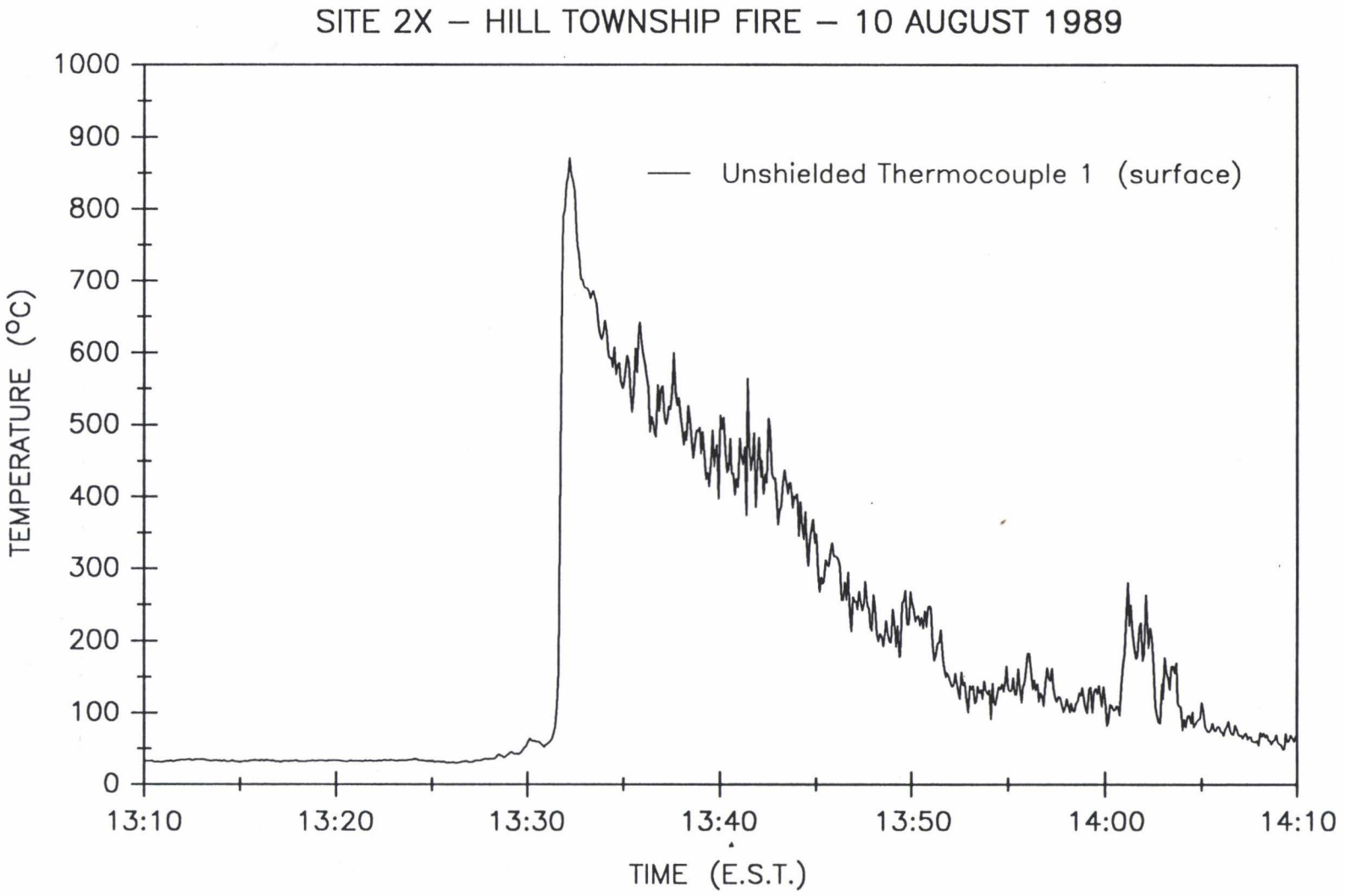

SITE 1B – HILL TOWNSHIP FIRE – 10 AUGUST 1989
Unshielded Thermocouple 6 (surface)
TEMPERATURE (°C)
1000
900
800
700
600
500
400
300
200
100
0
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)

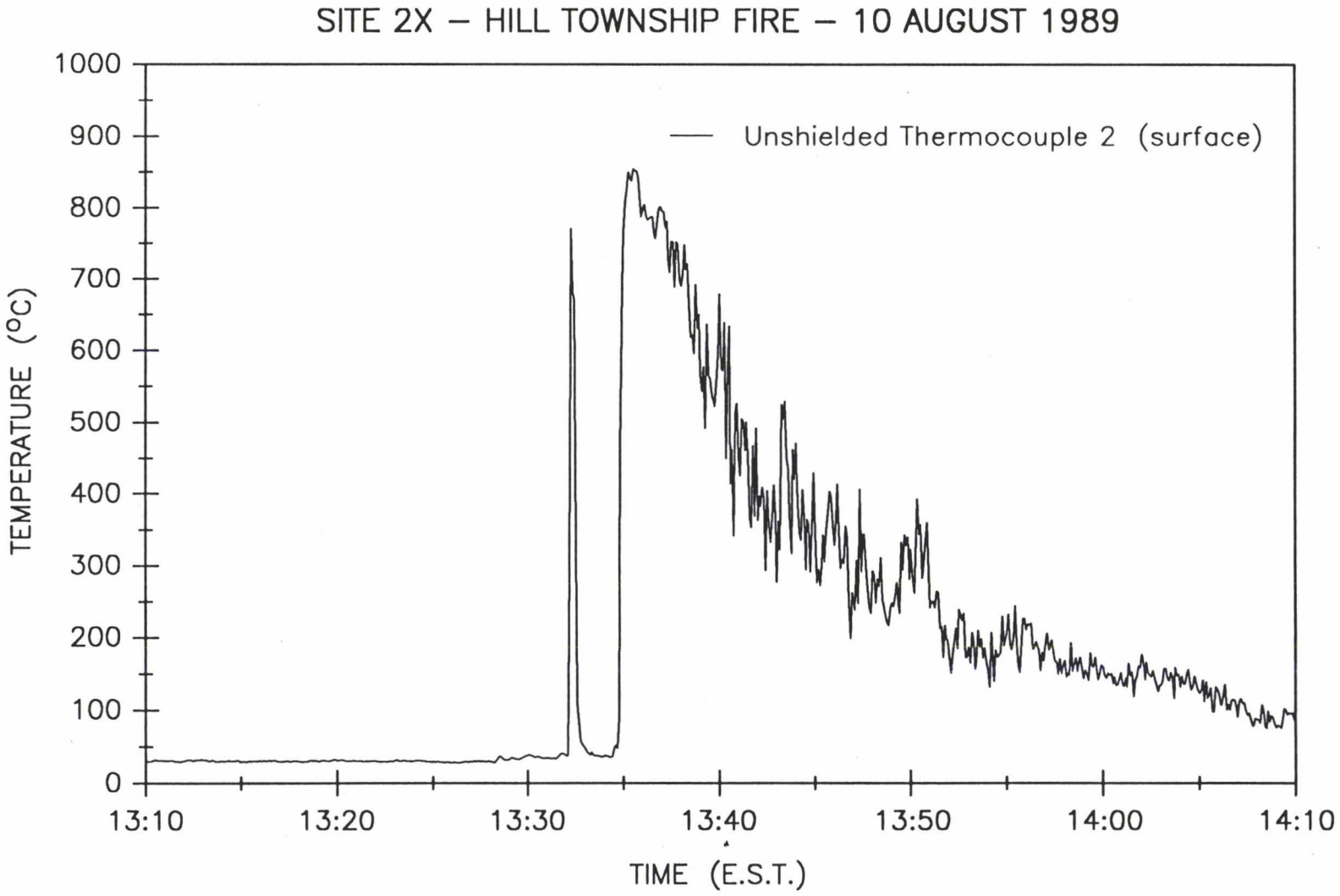

SITE 1B – HILL TOWNSHIP FIRE – 10 AUGUST 1989
Unshielded Thermocouple 7 (surface)
TEMPERATURE (°C)
1000
900
800
700
600
500
400
300
200
100
0
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)

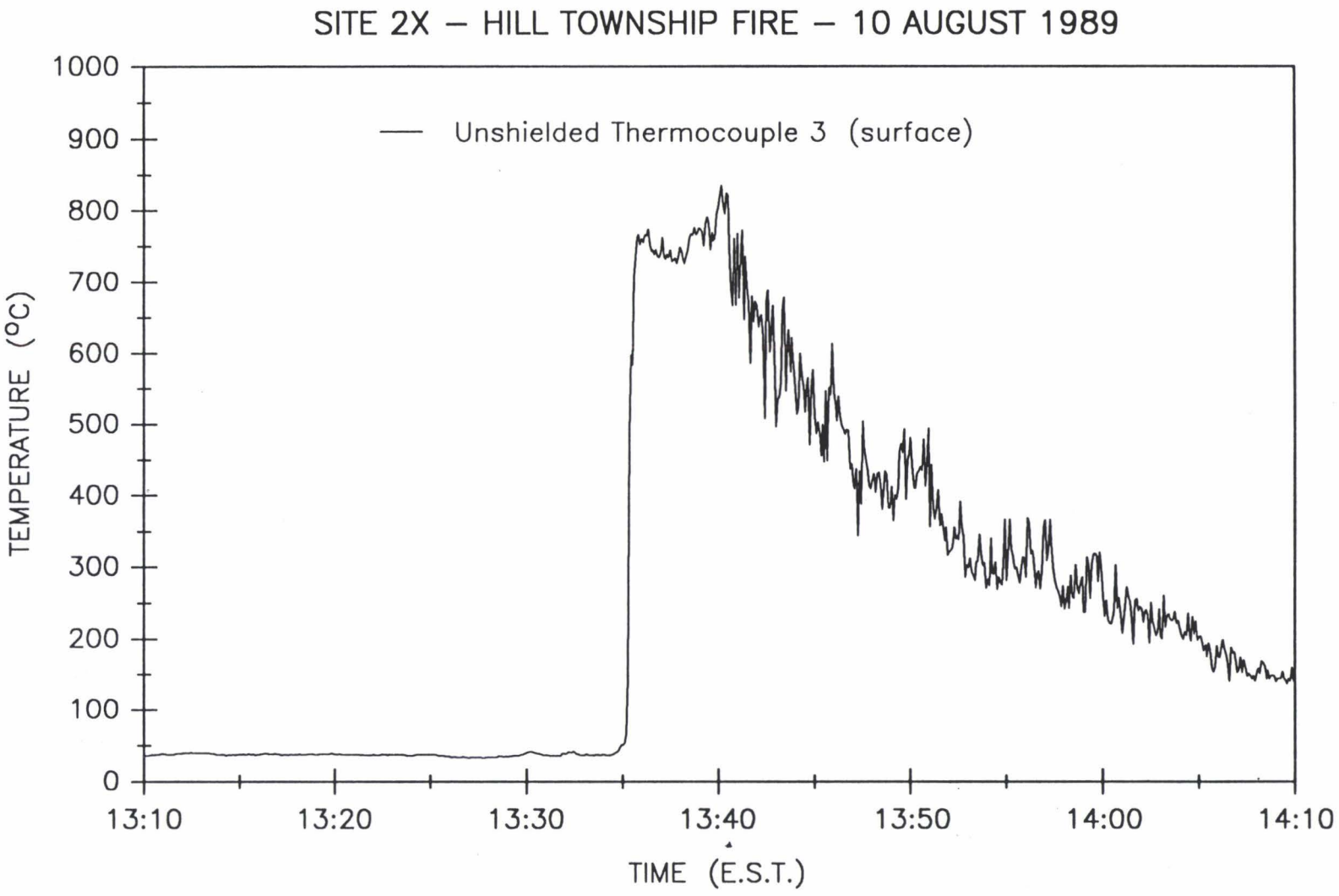

SITE 1B – HILL TOWNSHIP FIRE – 10 AUGUST 1989
Unshielded Thermocouple 8 (surface)
TEMPERATURE (°C)
1000
900
800
700
600
500
400
300
200
100
0
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)

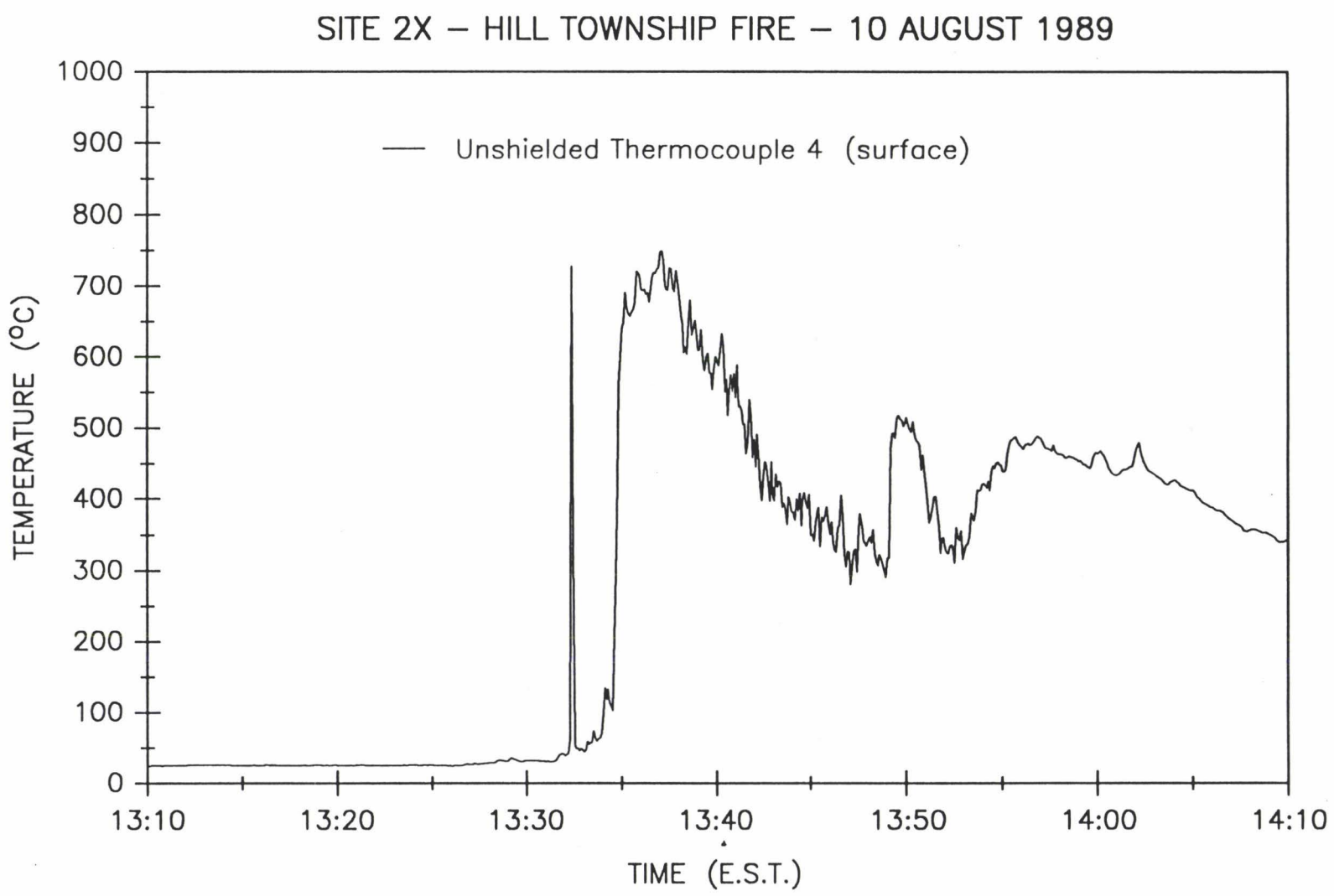

SITE 1B – HILL TOWNSHIP FIRE – 10 AUGUST 1989
Unshielded Thermocouple 9 (surface)
TEMPERATURE (°C)
1000
900
800
700
600
500
400
300
200
100
0
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)

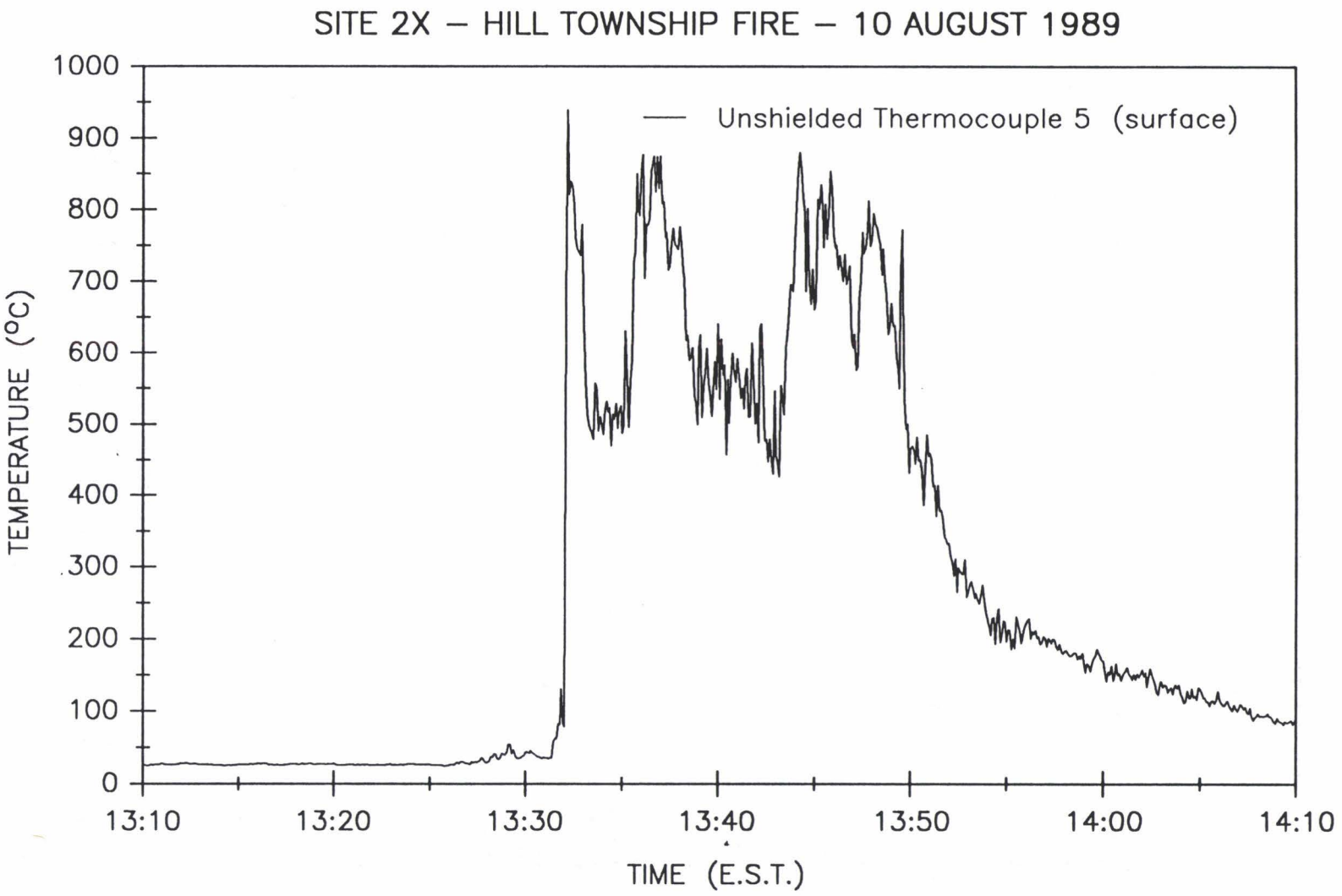

SITE 1B – HILL TOWNSHIP FIRE – 10 AUGUST 1989
Unshielded Thermocouple 10 (surface)
TEMPERATURE (°C)
1000
900
800
700
600
500
400
300
200
100
0
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)

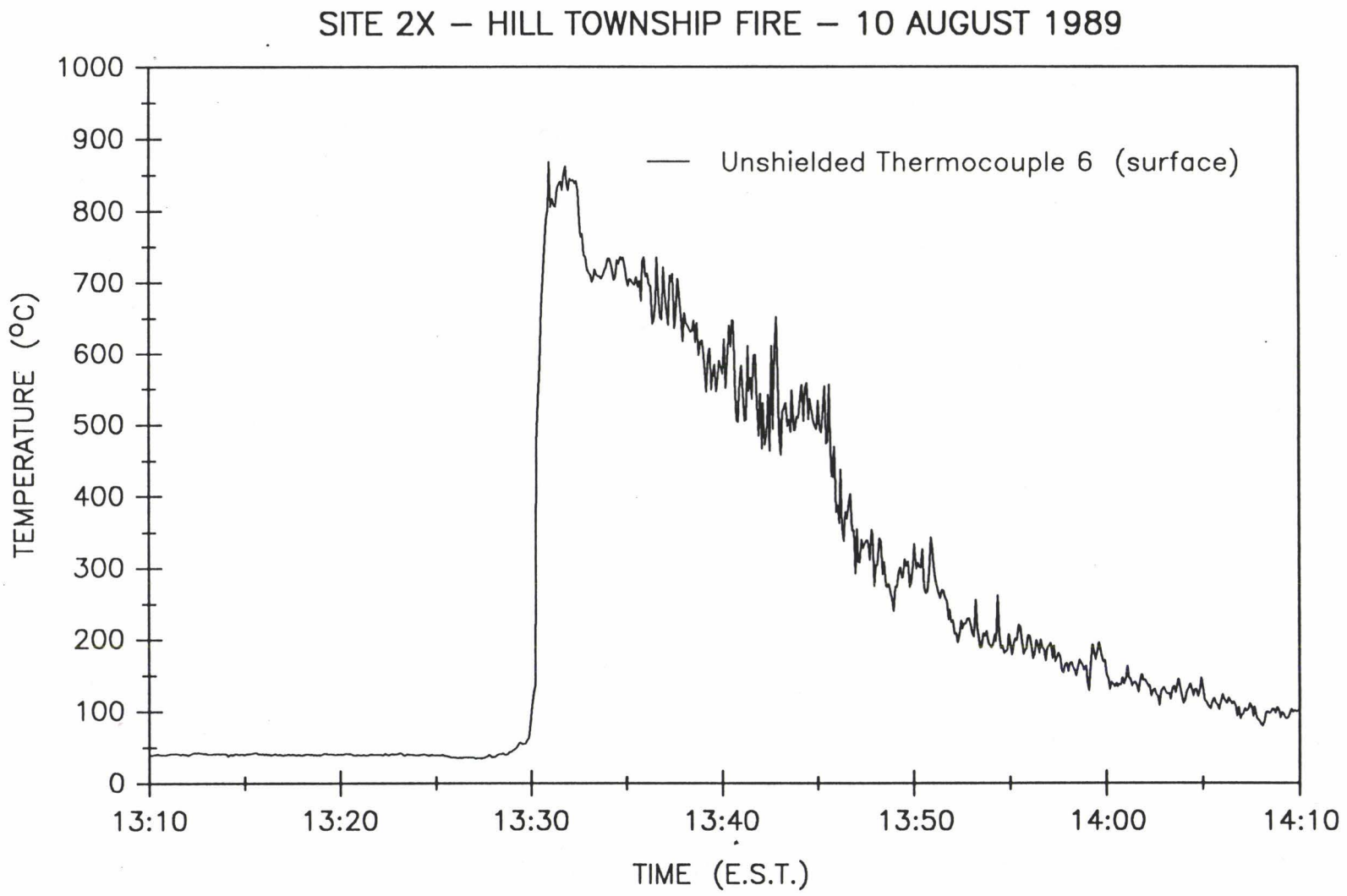

SITE 2X – HILL TOWNSHIP FIRE – 10 AUGUST 1989
TEMPERATURE (°C)
1000
900
800
700
600
500
400
300
200
100
0
Unshielded Thermocouple 1 (surface)
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)

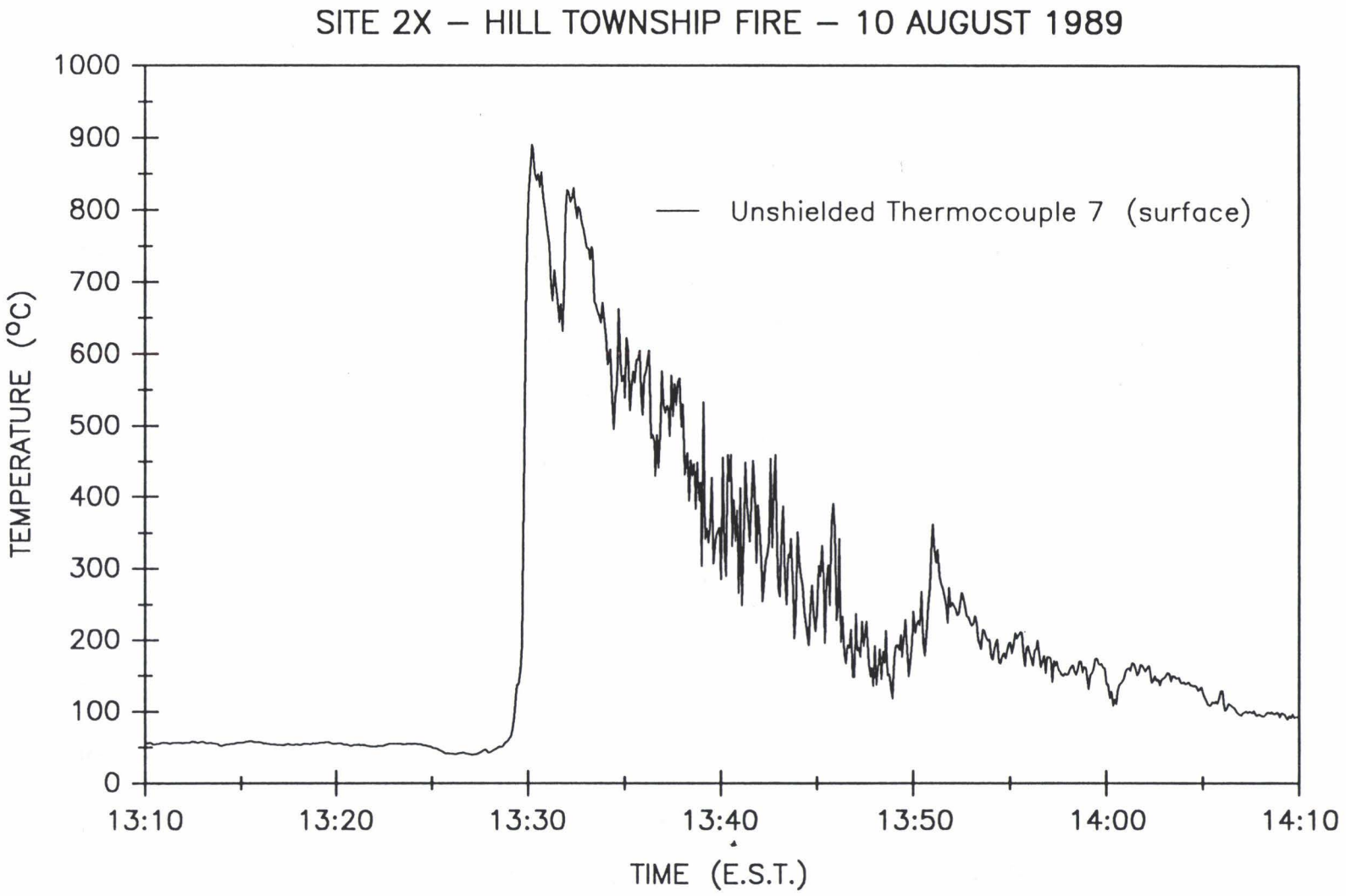

SITE 2X – HILL TOWNSHIP FIRE – 10 AUGUST 1989
Unshielded Thermocouple 2 (surface)
TEMPERATURE (°C)
1000
900
800
700
600
500
400
300
200
100
0
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)

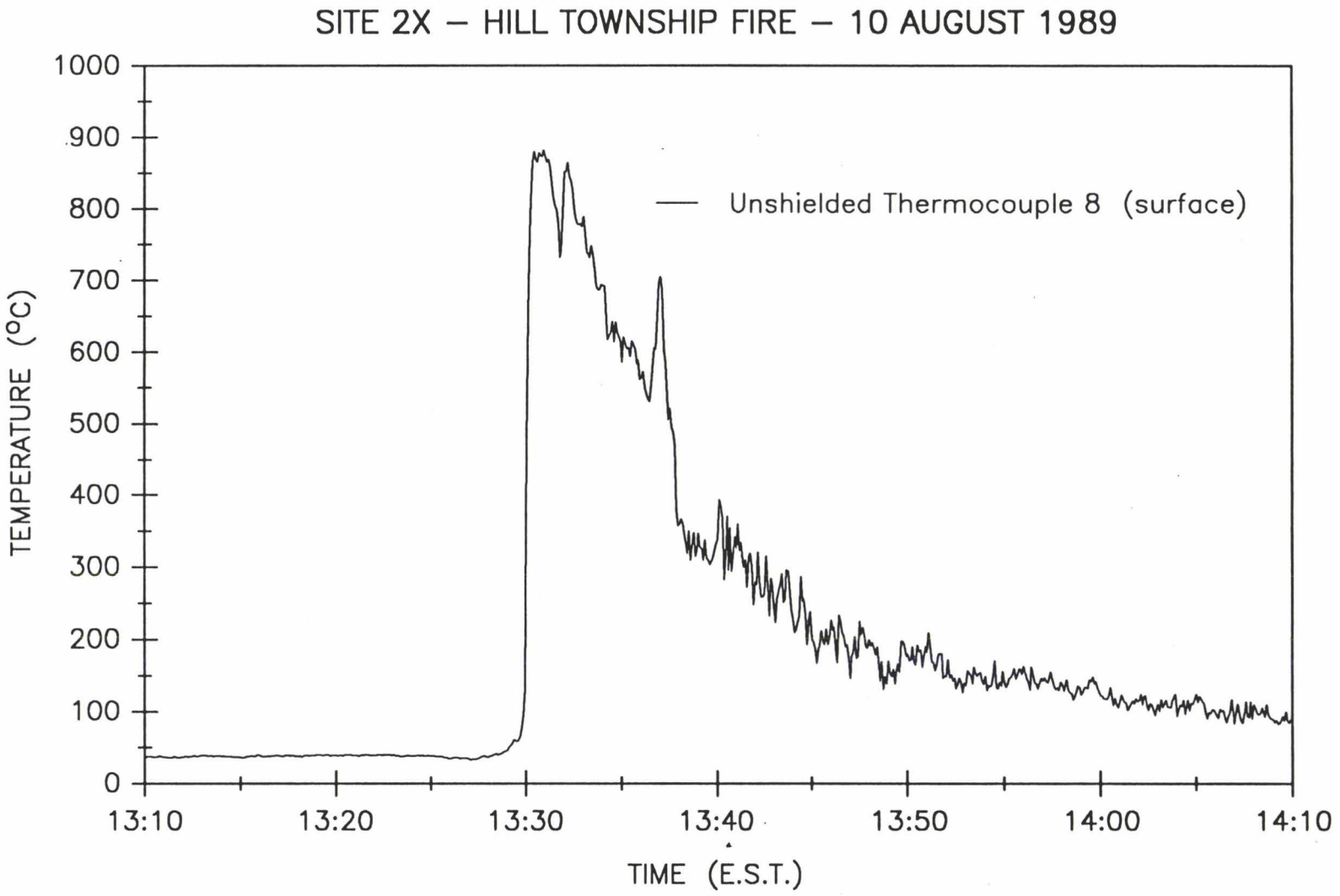

SITE 2X – HILL TOWNSHIP FIRE – 10 AUGUST 1989
Unshielded Thermocouple 3 (surface)
TEMPERATURE (°C)
1000
900
800
700
600
500
400
300
200
100
0
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)

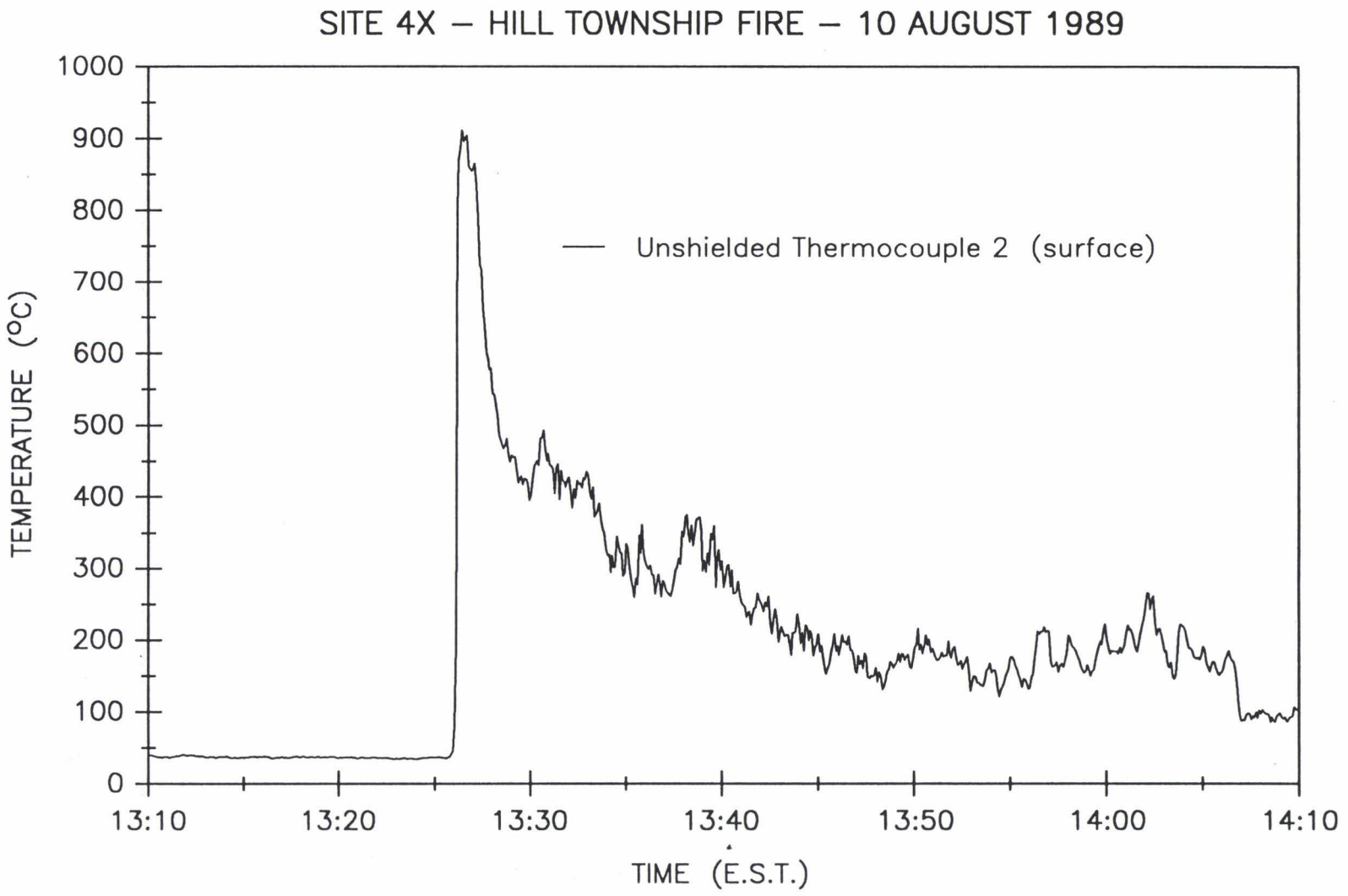

SITE 2X – HILL TOWNSHIP FIRE – 10 AUGUST 1989
Unshielded Thermocouple 4 (surface)
TEMPERATURE (°C)
1000
900
800
700
600
500
400
300
200
100
0
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)

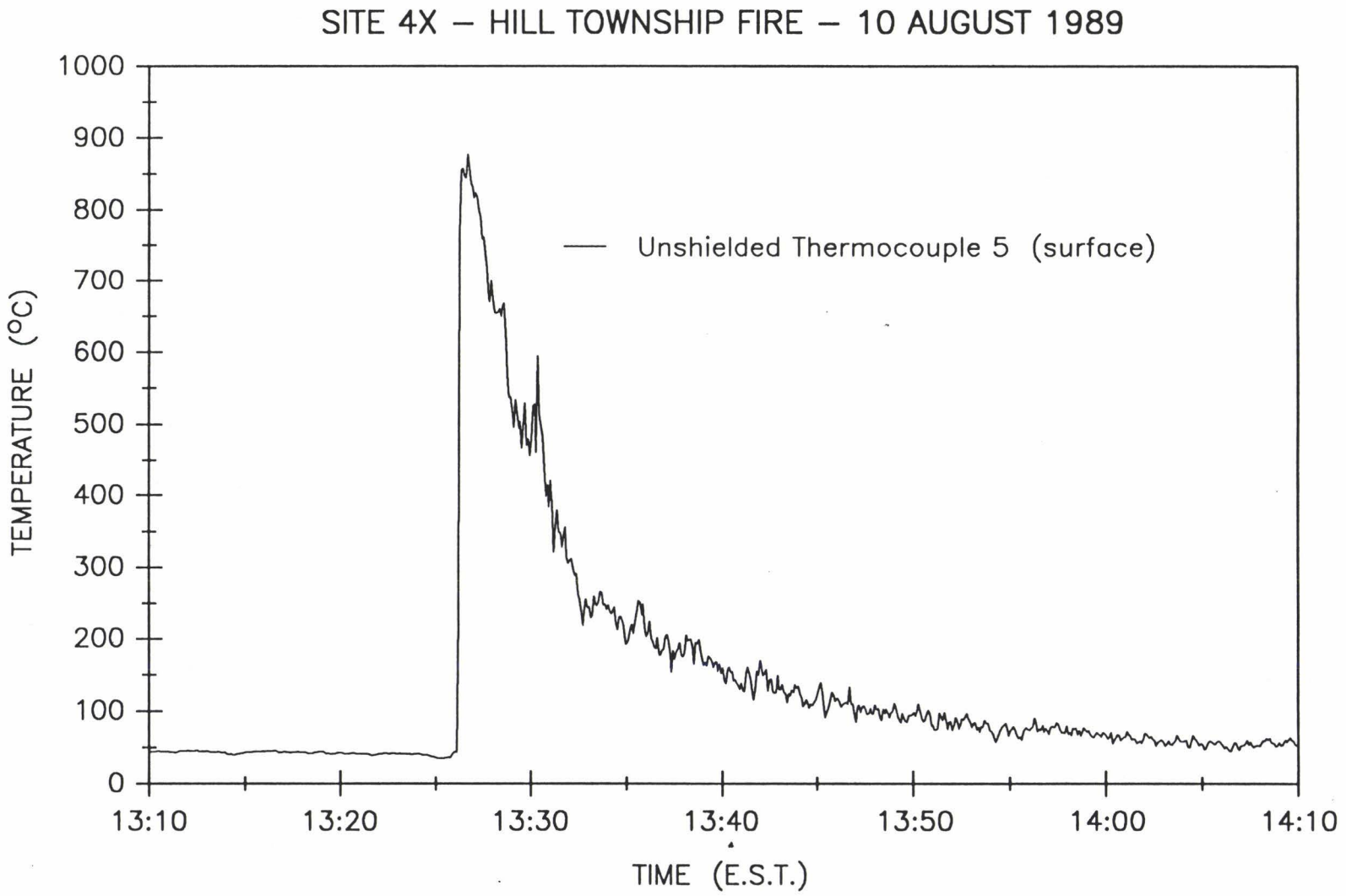

SITE 2X – HILL TOWNSHIP FIRE – 10 AUGUST 1989
Unshielded Thermocouple 5 (surface)
TEMPERATURE (°C)
1000
900
800
700
600
500
400
300
200
100
0
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)

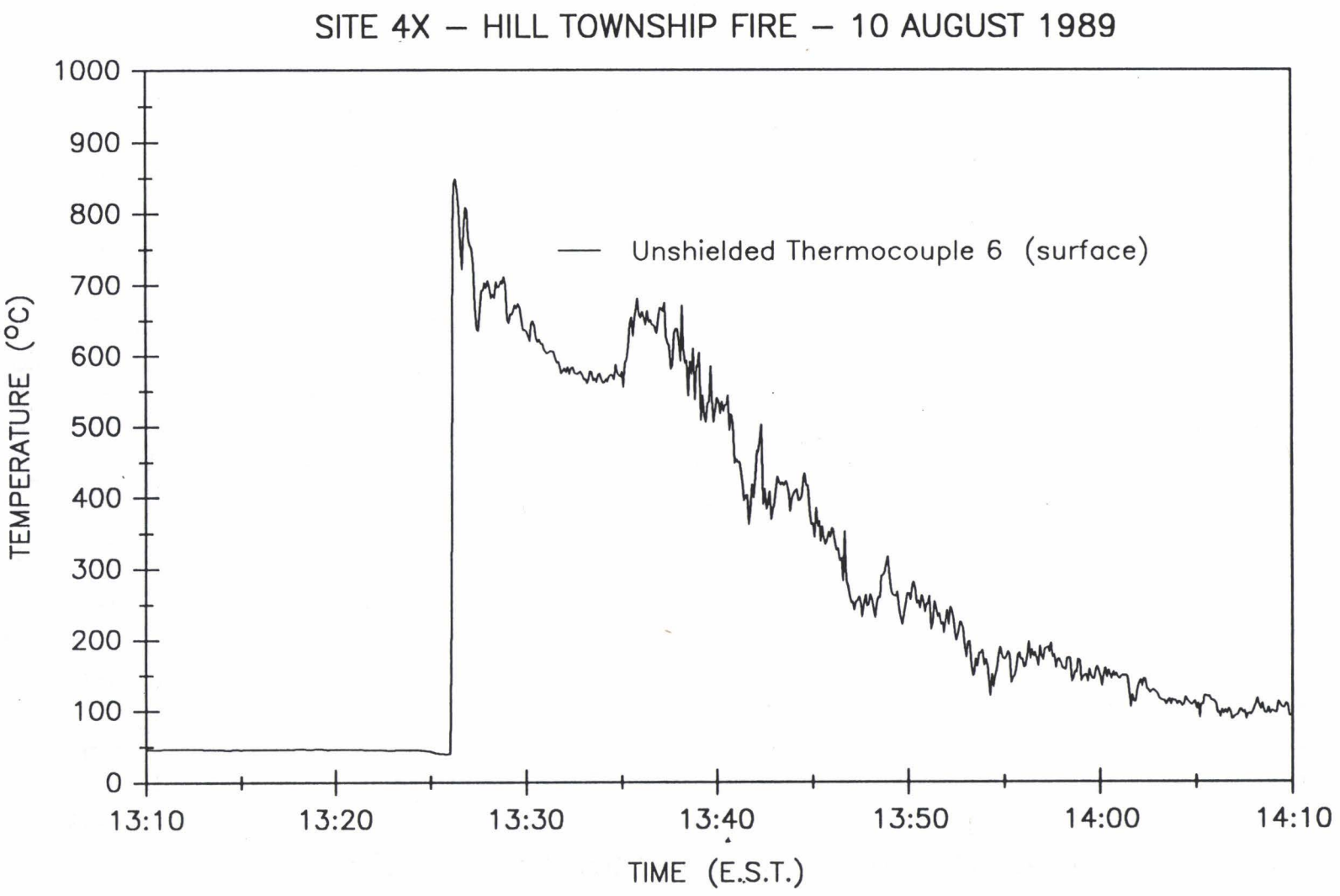

SITE 2X – HILL TOWNSHIP FIRE – 10 AUGUST 1989
Unshielded Thermocouple 6 (surface)
TEMPERATURE (°C)
1000
900
800
700
600
500
400
300
200
100
0
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)

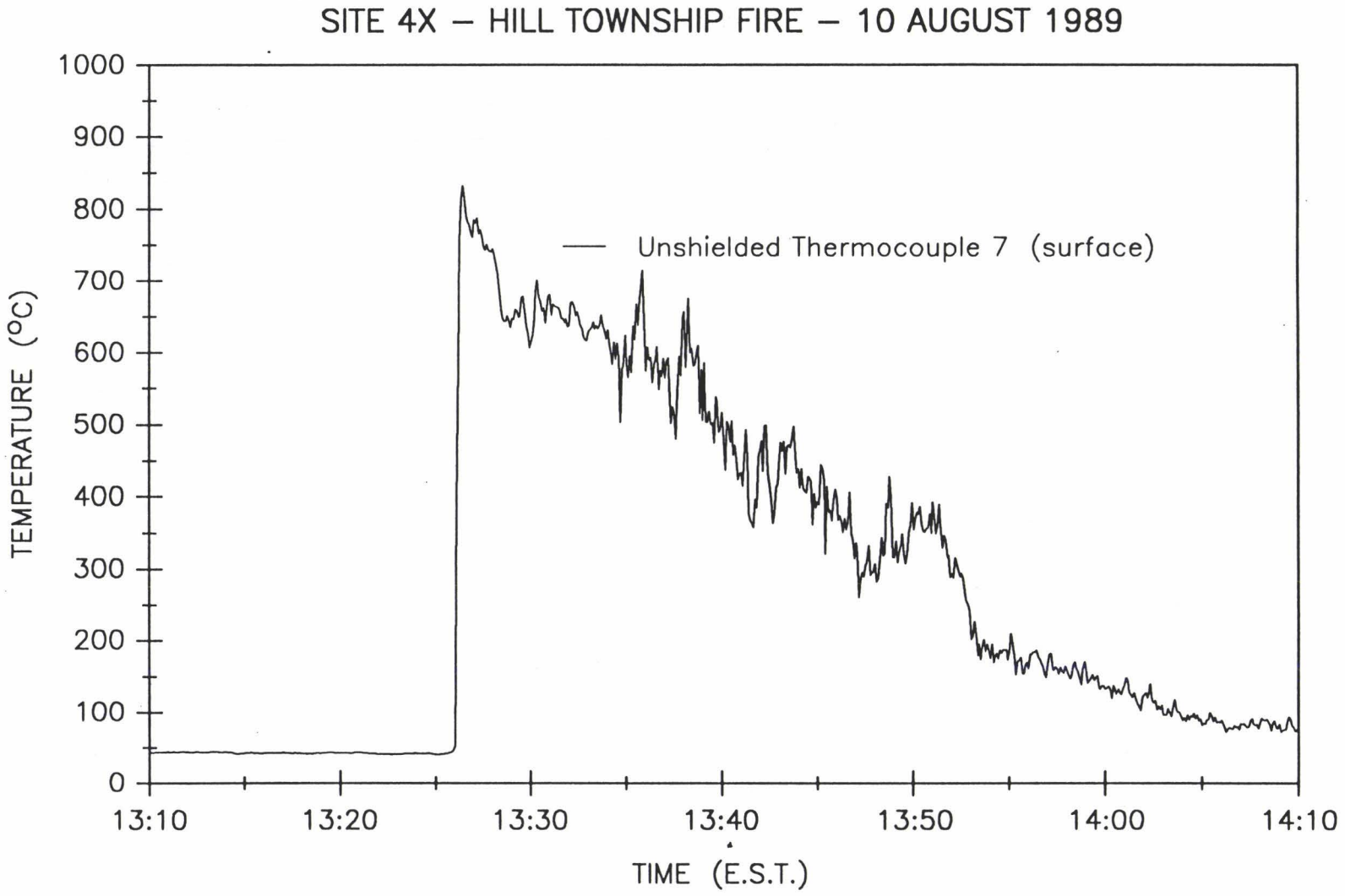

SITE 2X – HILL TOWNSHIP FIRE – 10 AUGUST 1989
1000
900
800
700
600
500
400
300
200
100
0
TEMPERATURE (°C)
Unshielded Thermocouple 7 (surface)
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)

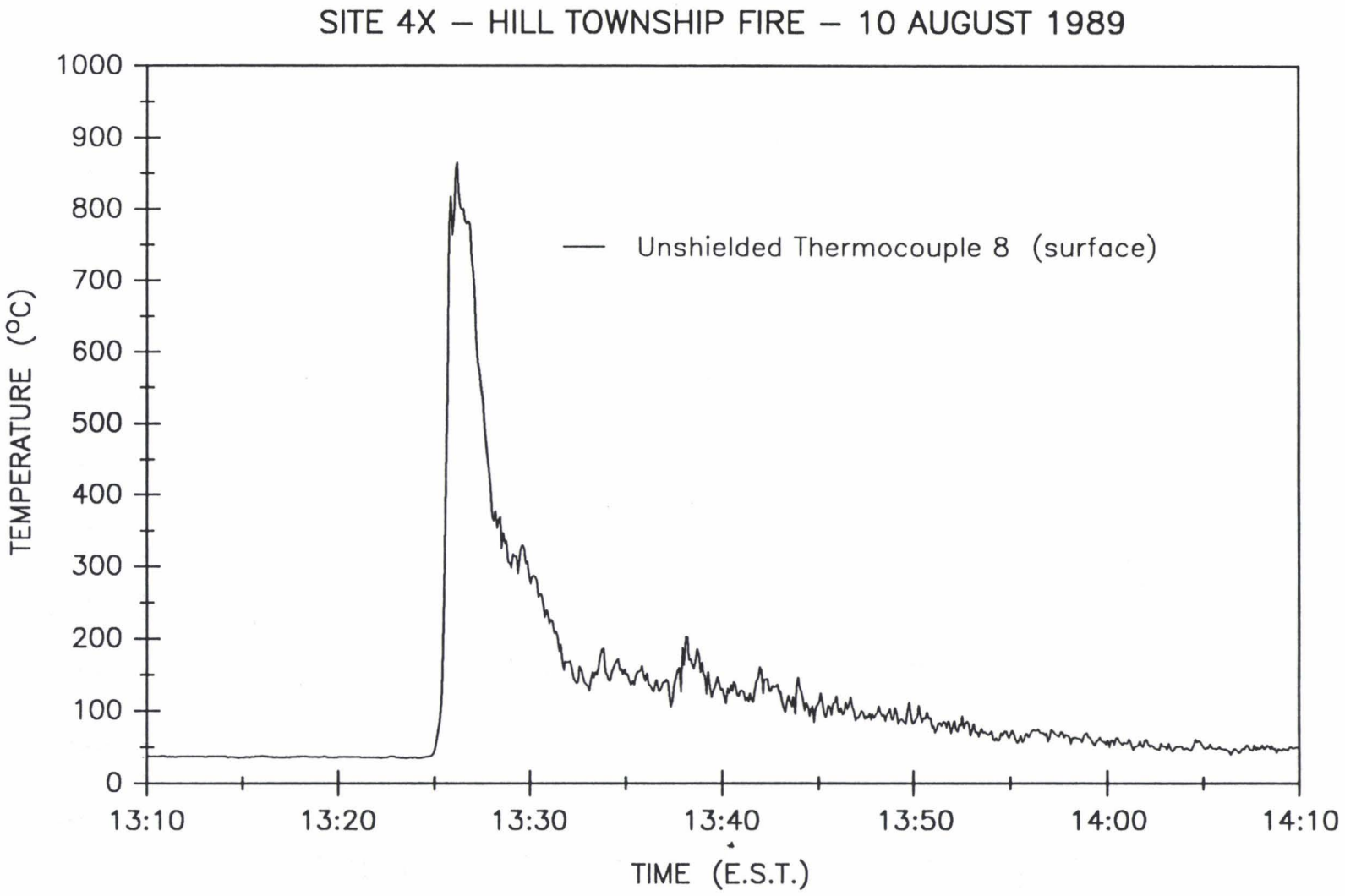

SITE 2X – HILL TOWNSHIP FIRE – 10 AUGUST 1989
TEMPERATURE (°C)
1000
900
800
700
600
500
400
300
200
100
0
Unshielded Thermocouple 8 (surface)
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)

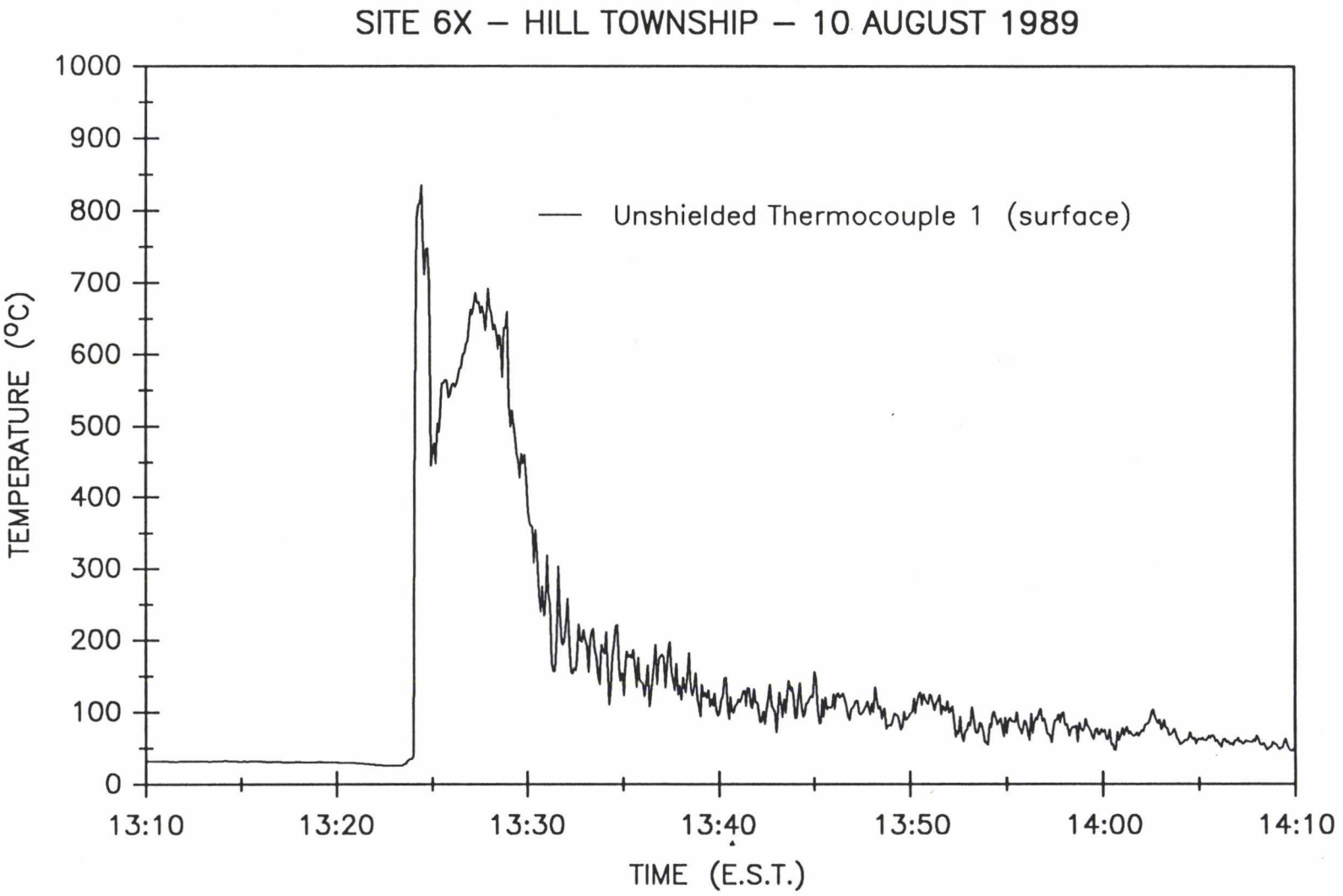

SITE 4X – HILL TOWNSHIP FIRE – 10 AUGUST 1989
TEMPERATURE (°C)
1000
900
800
700
600
500
400
300
200
100
0
Unshielded Thermocouple 2 (surface)
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)

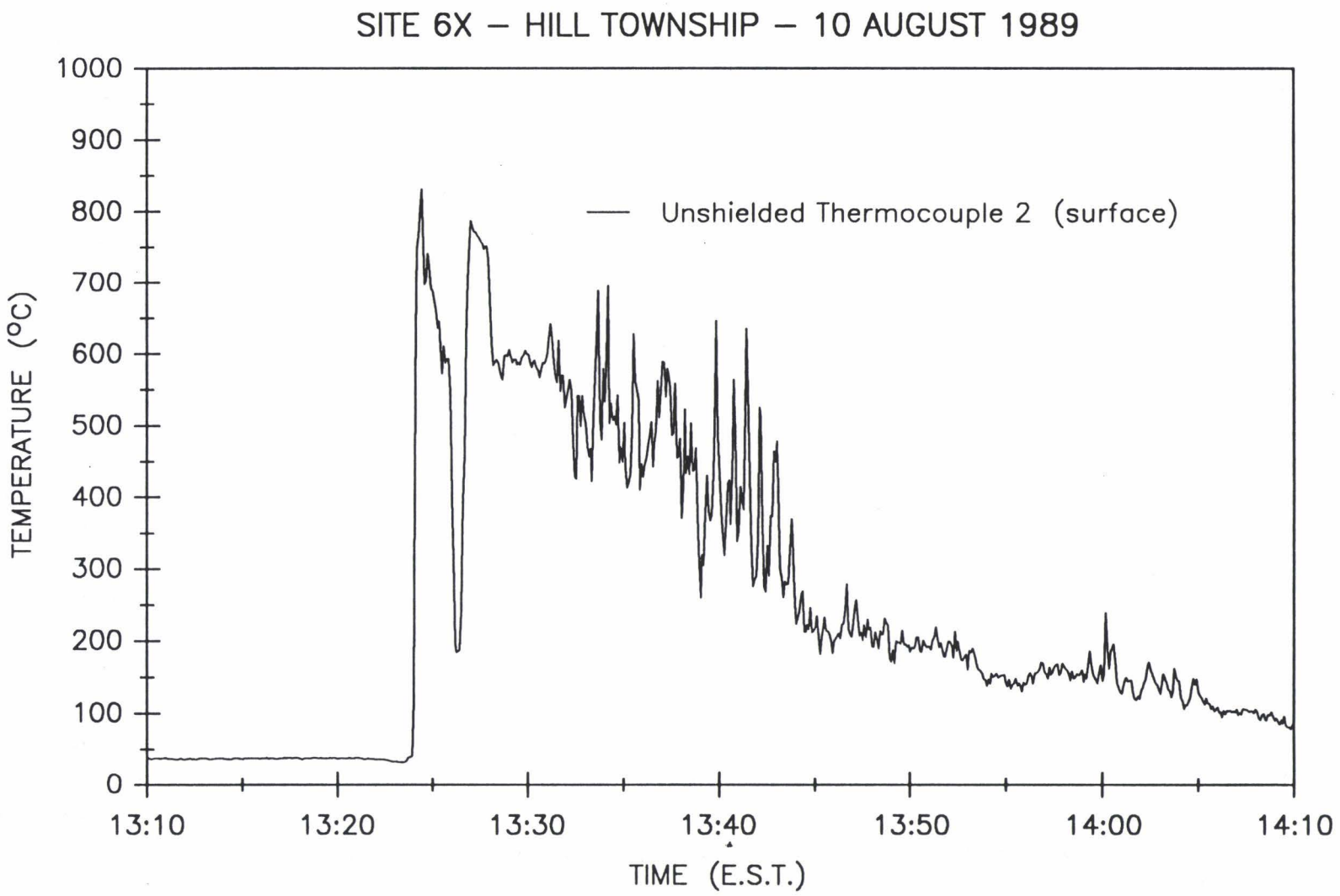

SITE 4X – HILL TOWNSHIP FIRE – 10 AUGUST 1989
1000
900
800
700
600
500
400
300
200
100
0
TEMPERATURE (°C)
Unshielded Thermocouple 5 (surface)
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)

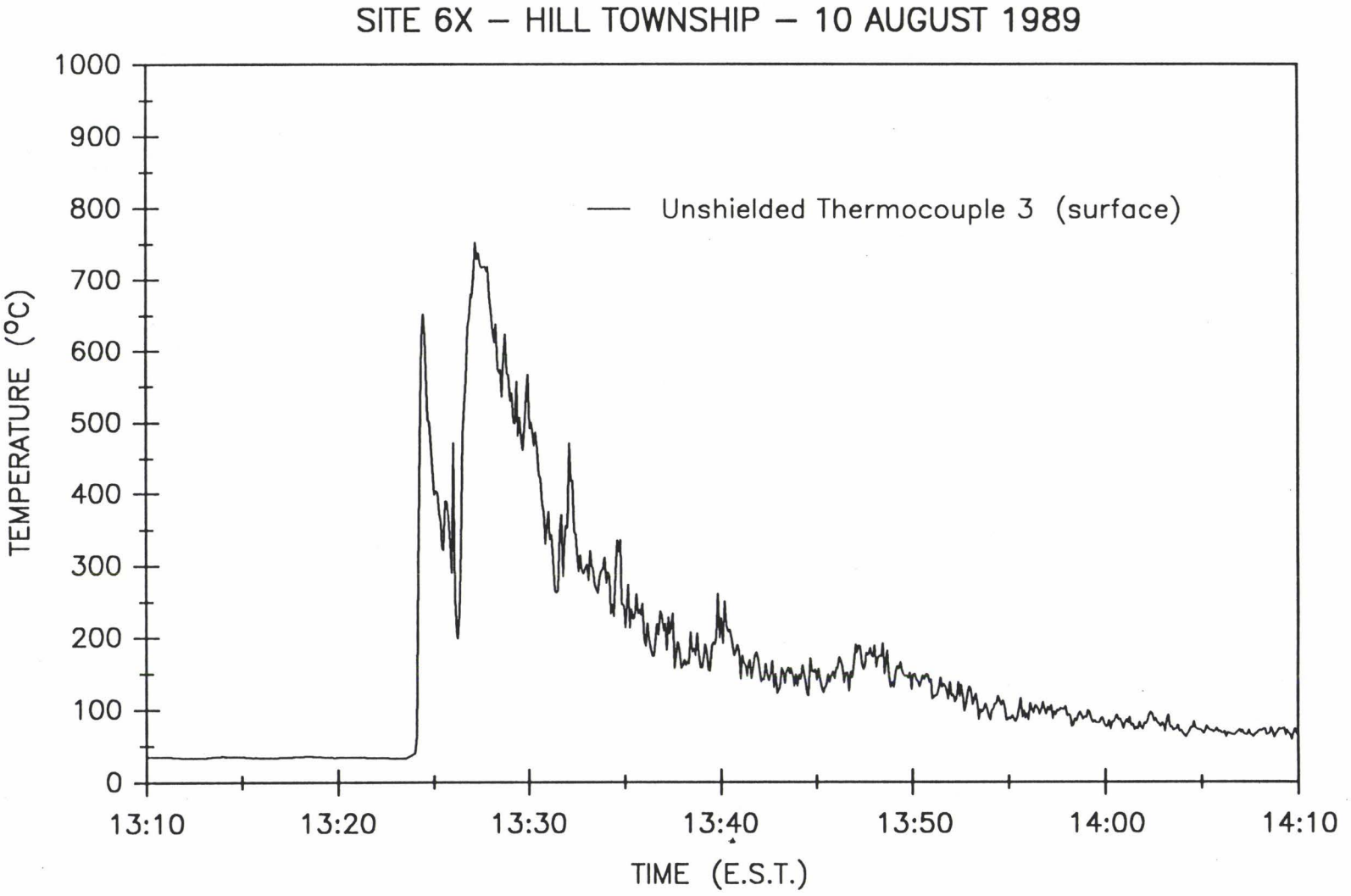

SITE 4X – HILL TOWNSHIP FIRE – 10 AUGUST 1989
TEMPERATURE (°C)
1000
900
800
700
600
500
400
300
200
100
0
Unshielded Thermocouple 6 (surface)
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)

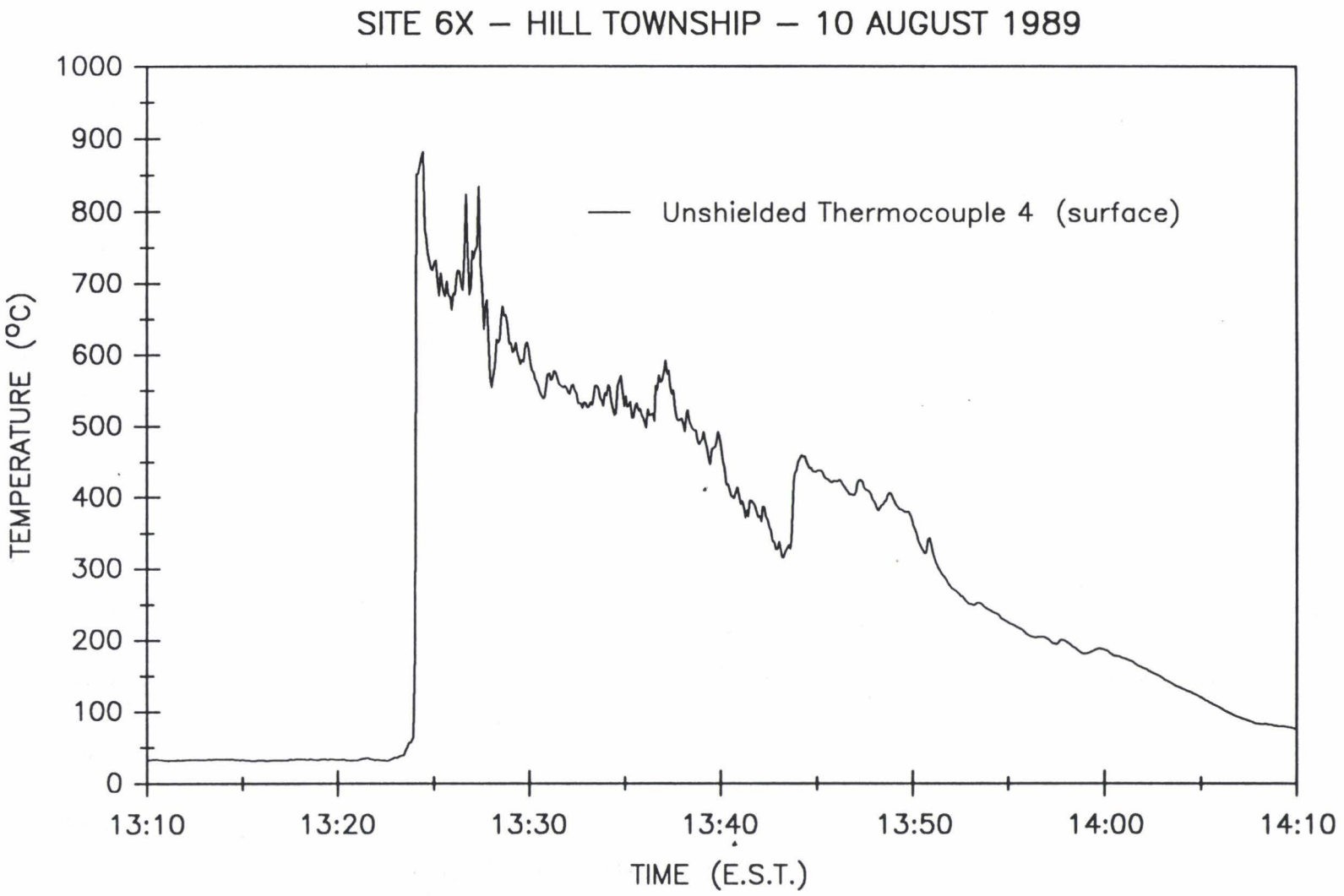

SITE 4X – HILL TOWNSHIP FIRE – 10 AUGUST 1989
1000
900
800
700
600
500
400
300
200
100
0
TEMPERATURE (°C)
Unshielded Thermocouple 7 (surface)
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)

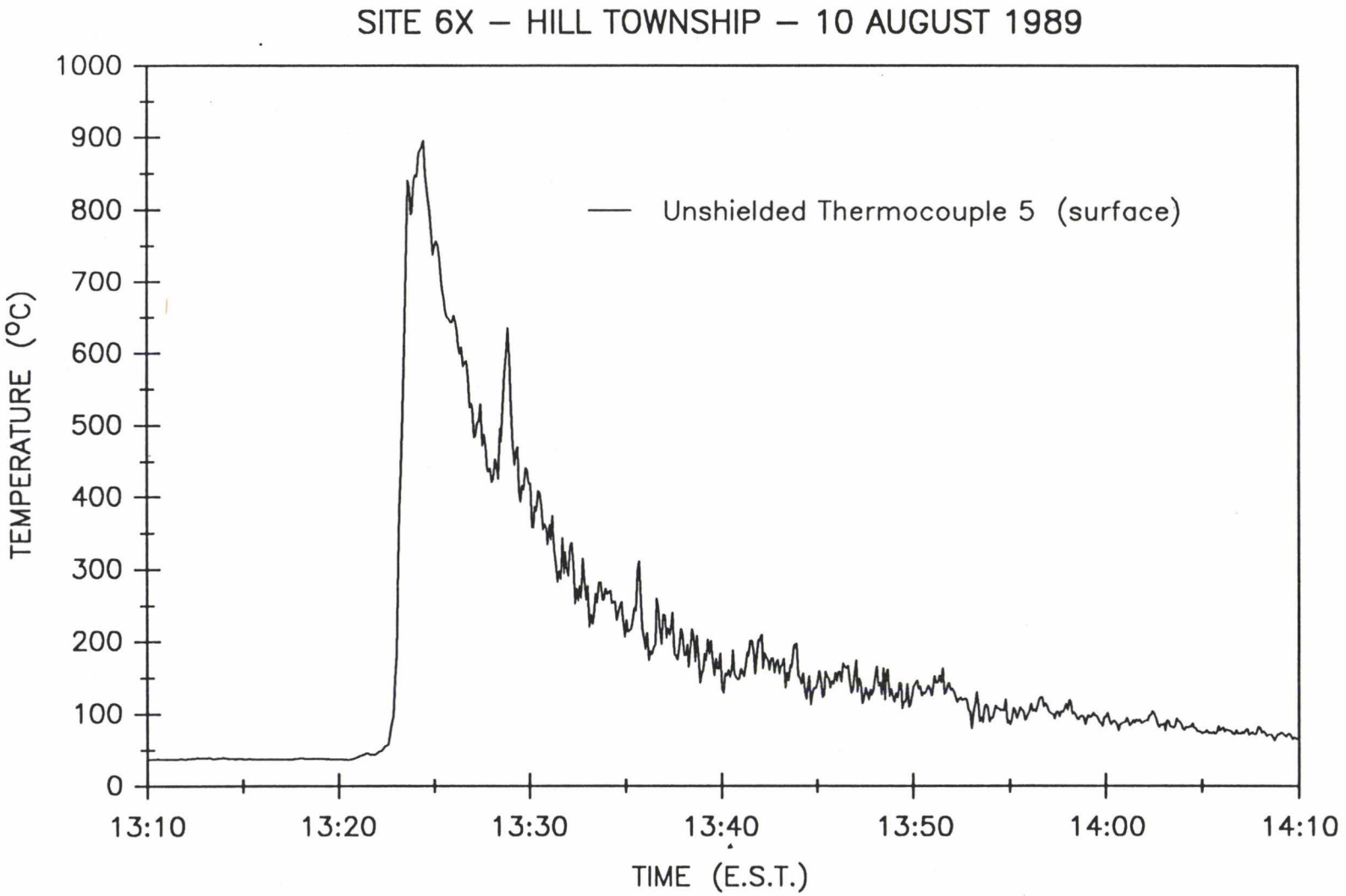

SITE 4X – HILL TOWNSHIP FIRE – 10 AUGUST 1989
TEMPERATURE (°C)
1000
900
800
700
600
500
400
300
200
100
0
Unshielded Thermocouple 8 (surface)
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)

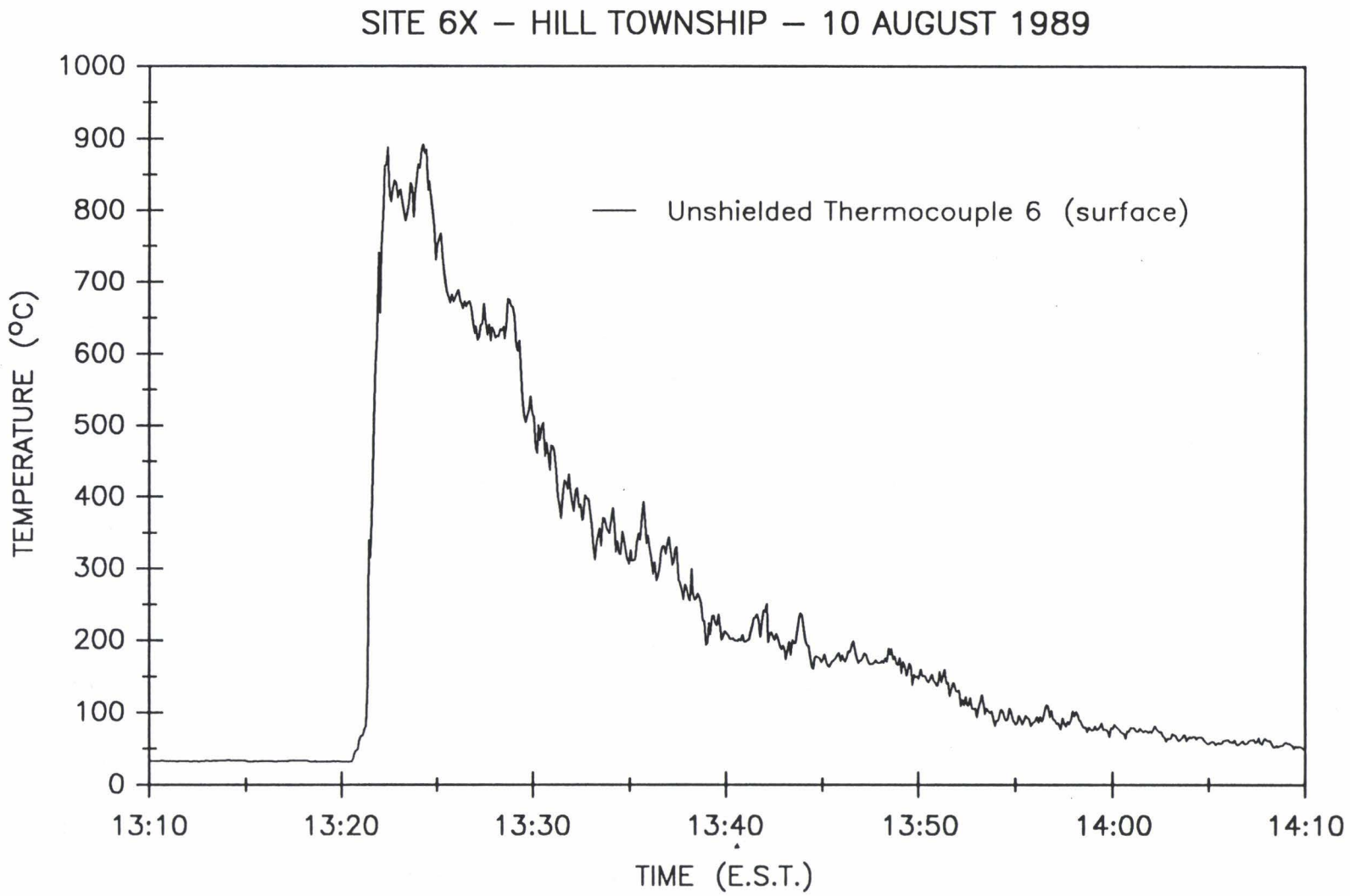

SITE 6X – HILL TOWNSHIP – 10 AUGUST 1989
1000
900
800
700
600
500
400
300
200
100
0
TEMPERATURE (°C)
Unshielded Thermocouple 1 (surface)
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)

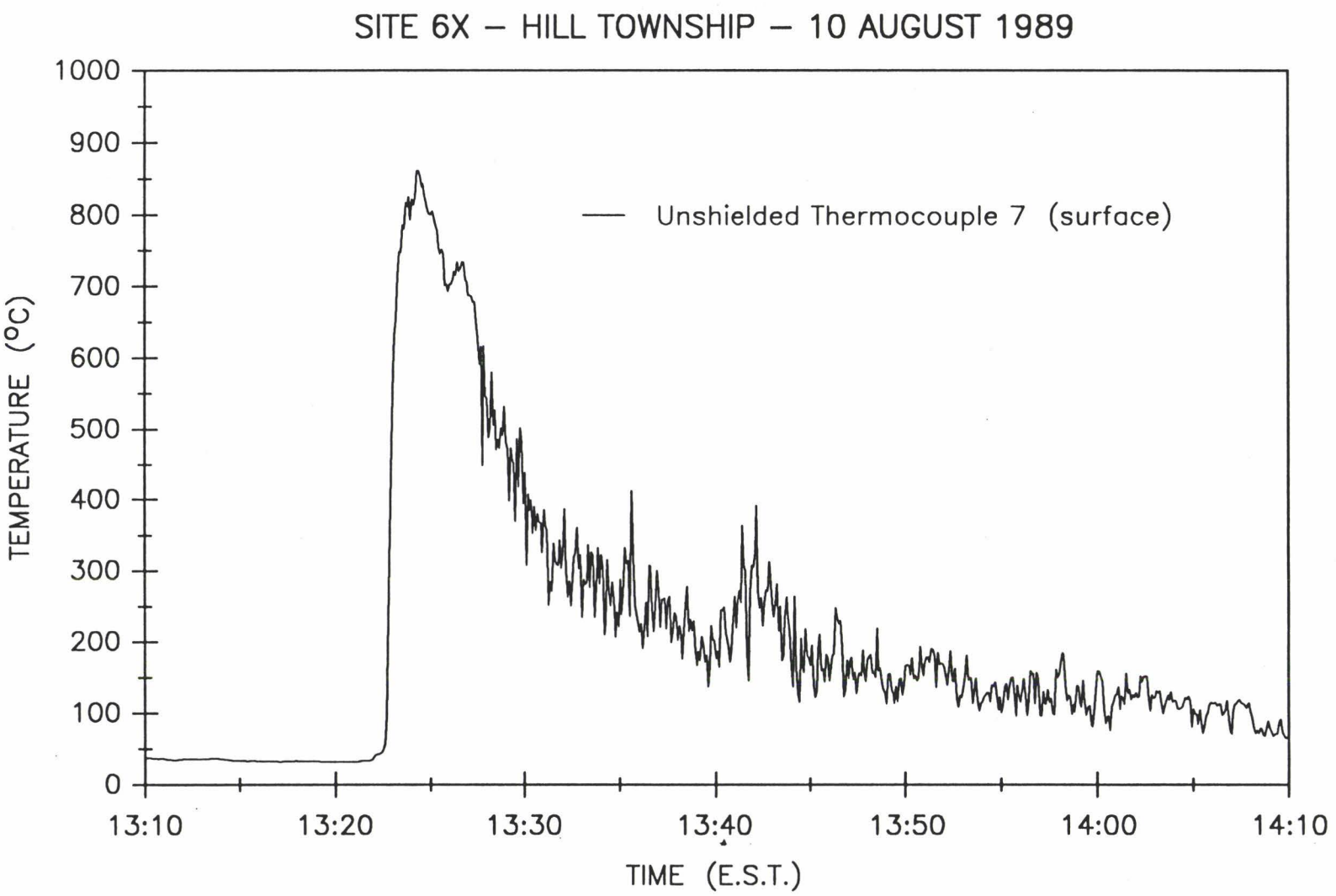

SITE 6X – HILL TOWNSHIP – 10 AUGUST 1989
Unshielded Thermocouple 2 (surface)
TEMPERATURE (°C)
1000
900
800
700
600
500
400
300
200
100
0
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)

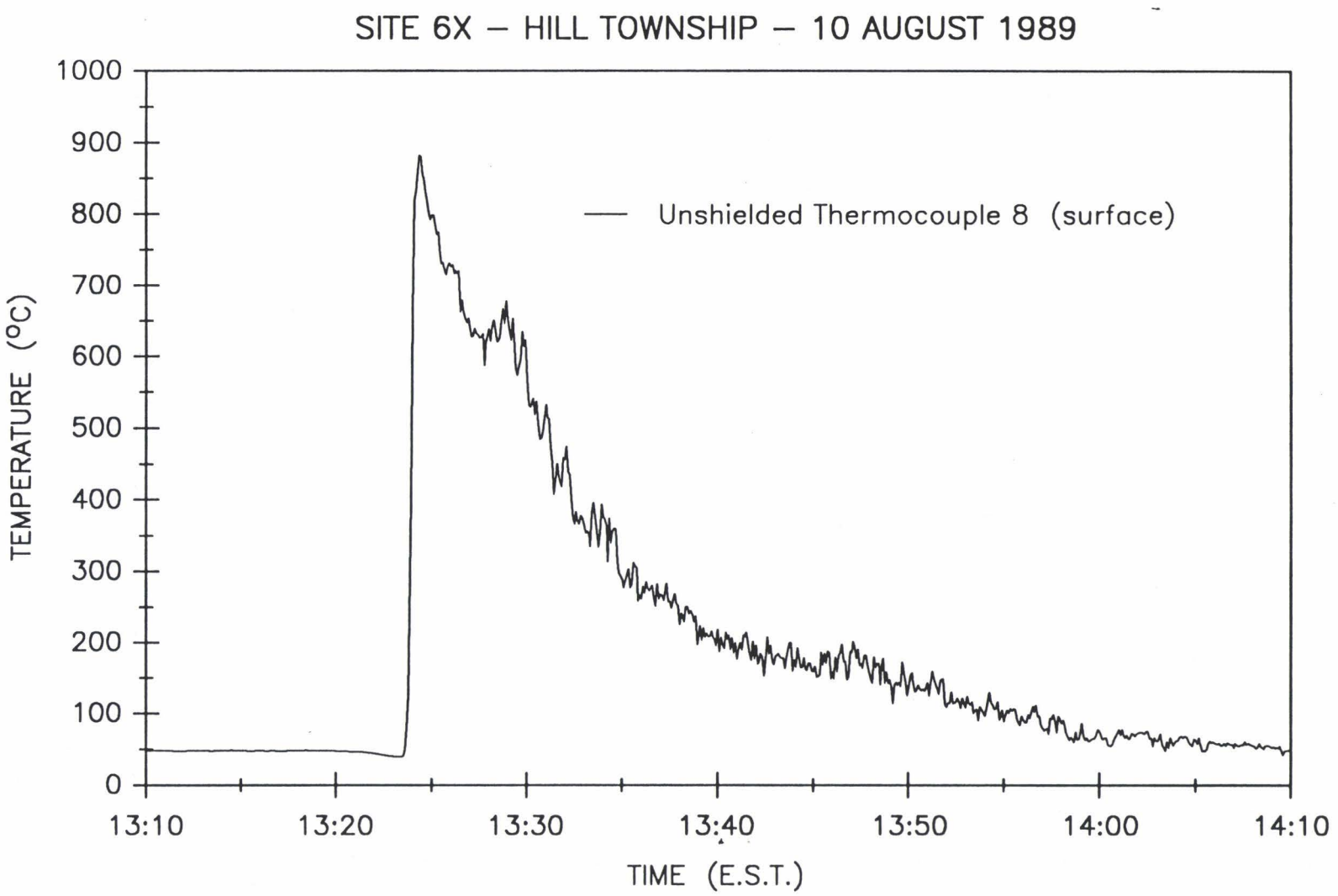

SITE 6X – HILL TOWNSHIP – 10 AUGUST 1989
1000
900
800
700
600
500
400
300
200
100
0
TEMPERATURE (°C)
Unshielded Thermocouple 3 (surface)
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)


SITE 6X – HILL TOWNSHIP – 10 AUGUST 1989
TEMPERATURE (°C)
1000
900
800
700
600
500
400
300
200
100
0
Unshielded Thermocouple 4 (surface)
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)


SITE 6X – HILL TOWNSHIP – 10 AUGUST 1989
1000
900
800
700
600
500
400
300
200
100
0
TEMPERATURE (°C)
Unshielded Thermocouple 5 (surface)
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)


SITE 6X – HILL TOWNSHIP – 10 AUGUST 1989
1000
900
800
700
600
500
400
300
200
100
0
TEMPERATURE (°C)
Unshielded Thermocouple 6 (surface)
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)


SITE 6X – HILL TOWNSHIP – 10 AUGUST 1989
1000
900
800
700
600
500
400
300
200
100
0
TEMPERATURE (°C)
Unshielded Thermocouple 7 (surface)
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)


SITE 6X – HILL TOWNSHIP – 10 AUGUST 1989
TEMPERATURE (°C)
1000
900
800
700
600
500
400
300
200
100
0
Unshielded Thermocouple 8 (surface)
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)

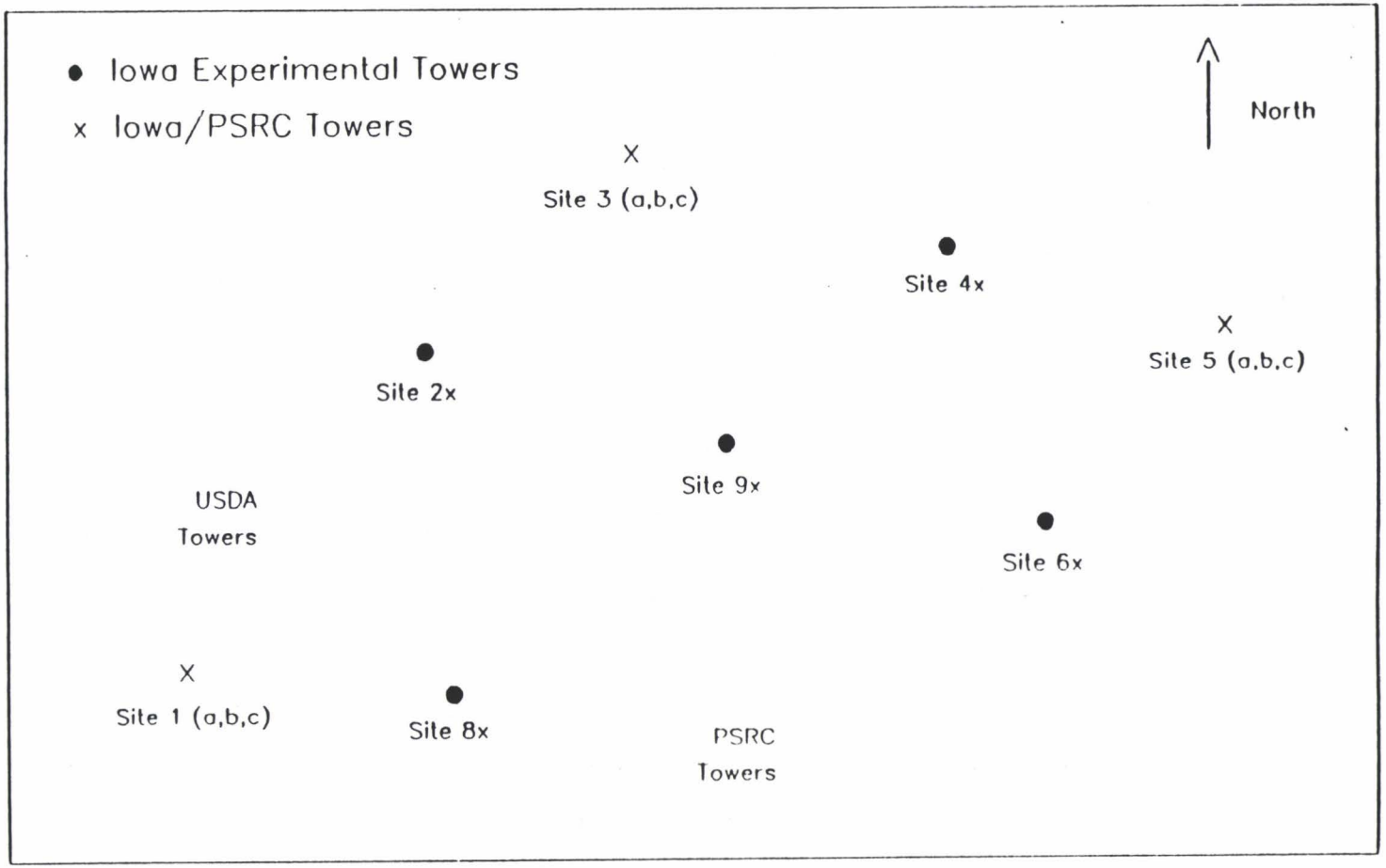
GOAL 5 (OBJECTIVE I)

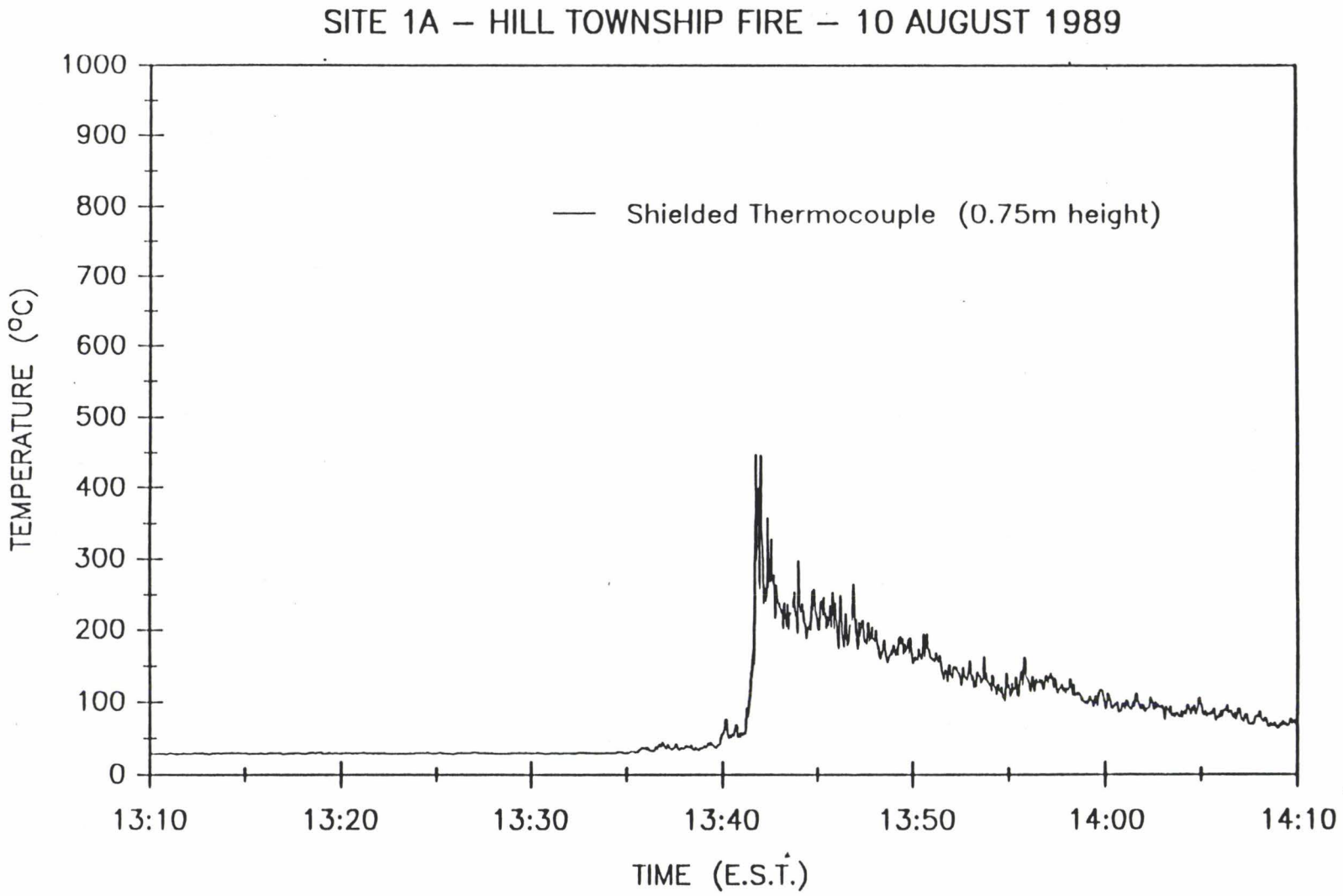
TO OBTAIN AND ANALYZE INTEGRATED VERTICAL PROFILE TEMPERATURE DATA COLLECTED ON THE TOWERS

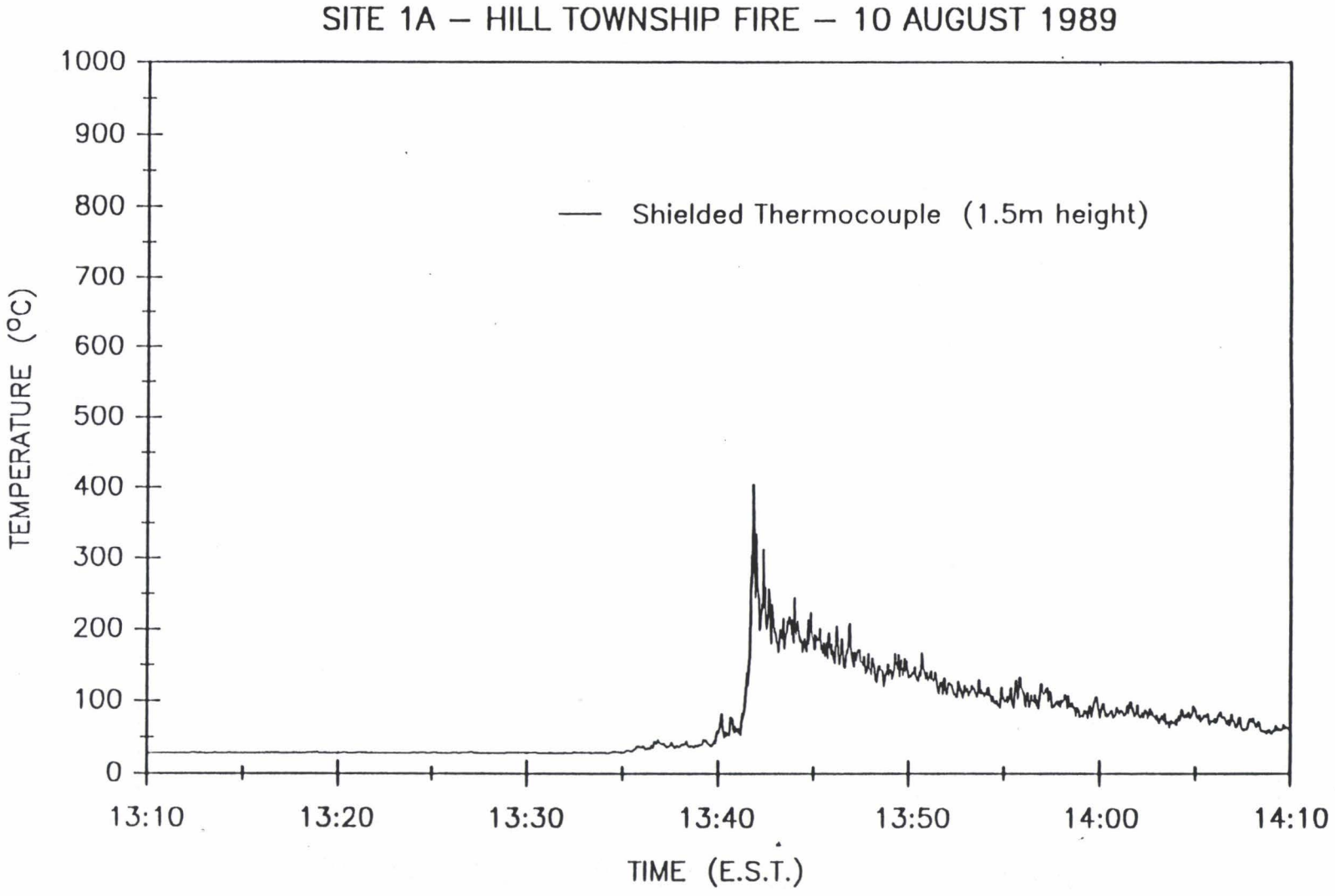
PROGRESS TO DATE:

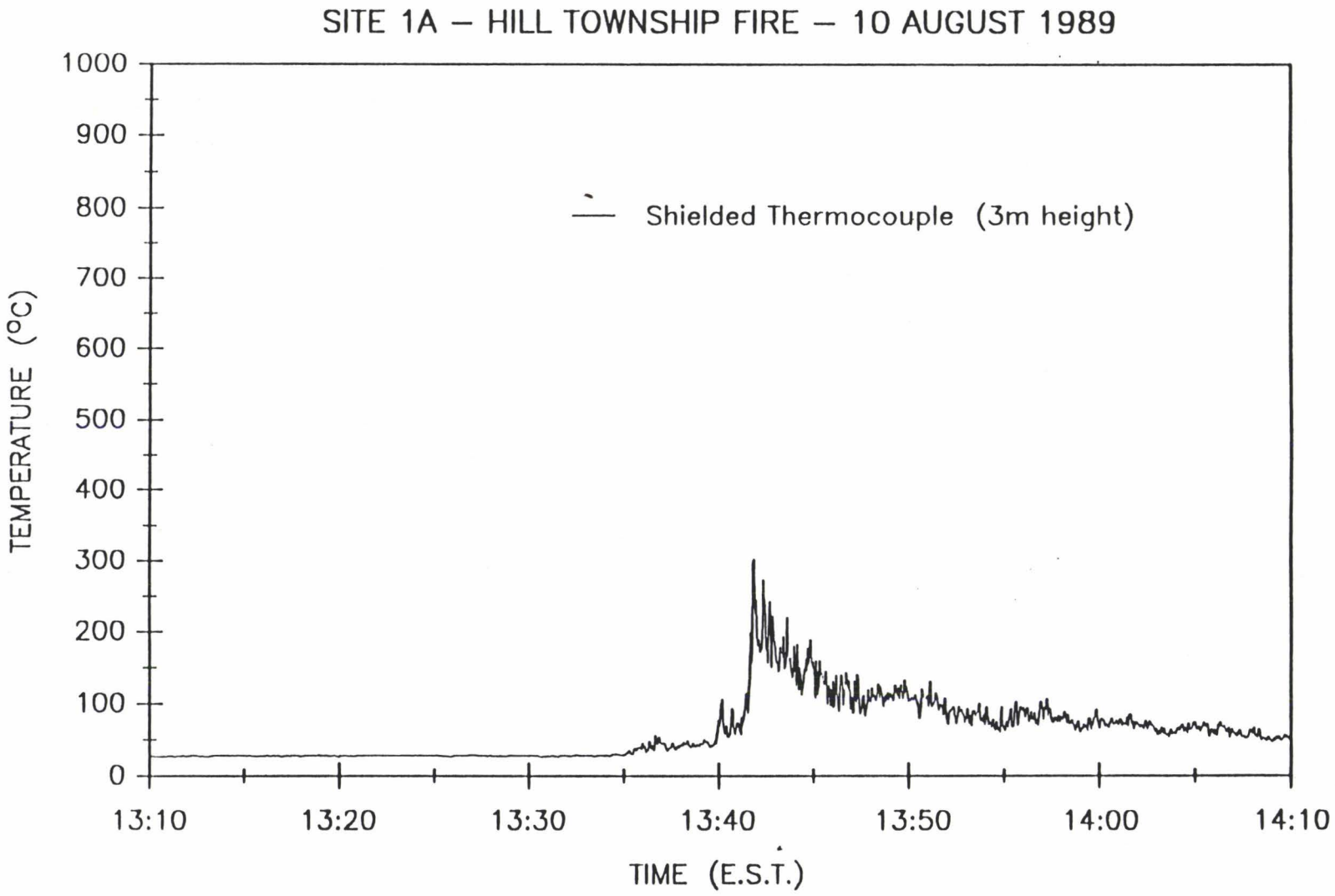
To date all of the data has been reduced and graphed and comparisons of rates of change are underway. Comparisons of data from shielded and unshielded towers are also being carried out. Tower configurations, locations, standardized time base graphs are provided in the following pages and examples of the rates of change are provided.

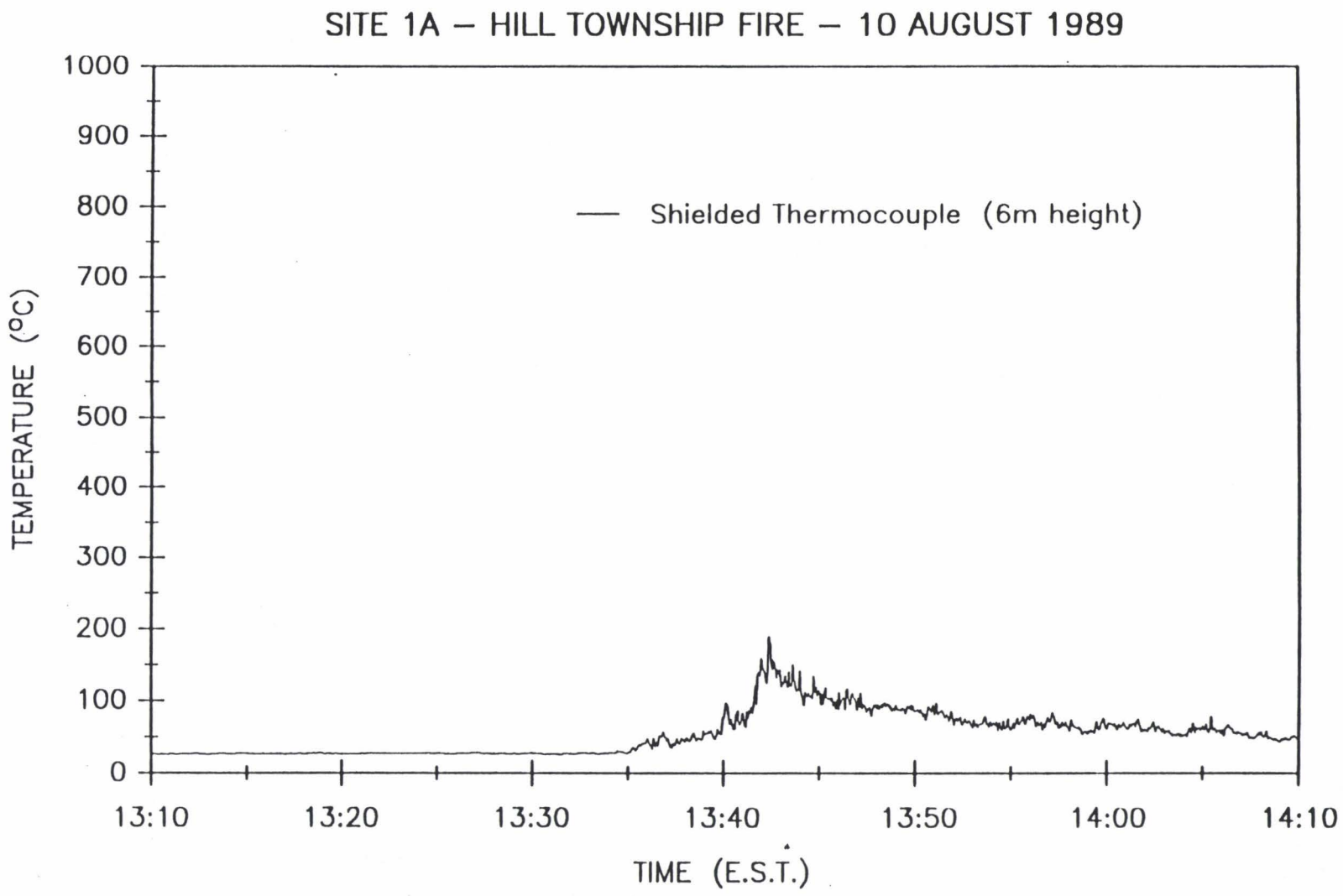
RELATIVE LOCATION OF IOWA EXPERIMENTAL TOWERS, HILL TOWNSHIP FIRE

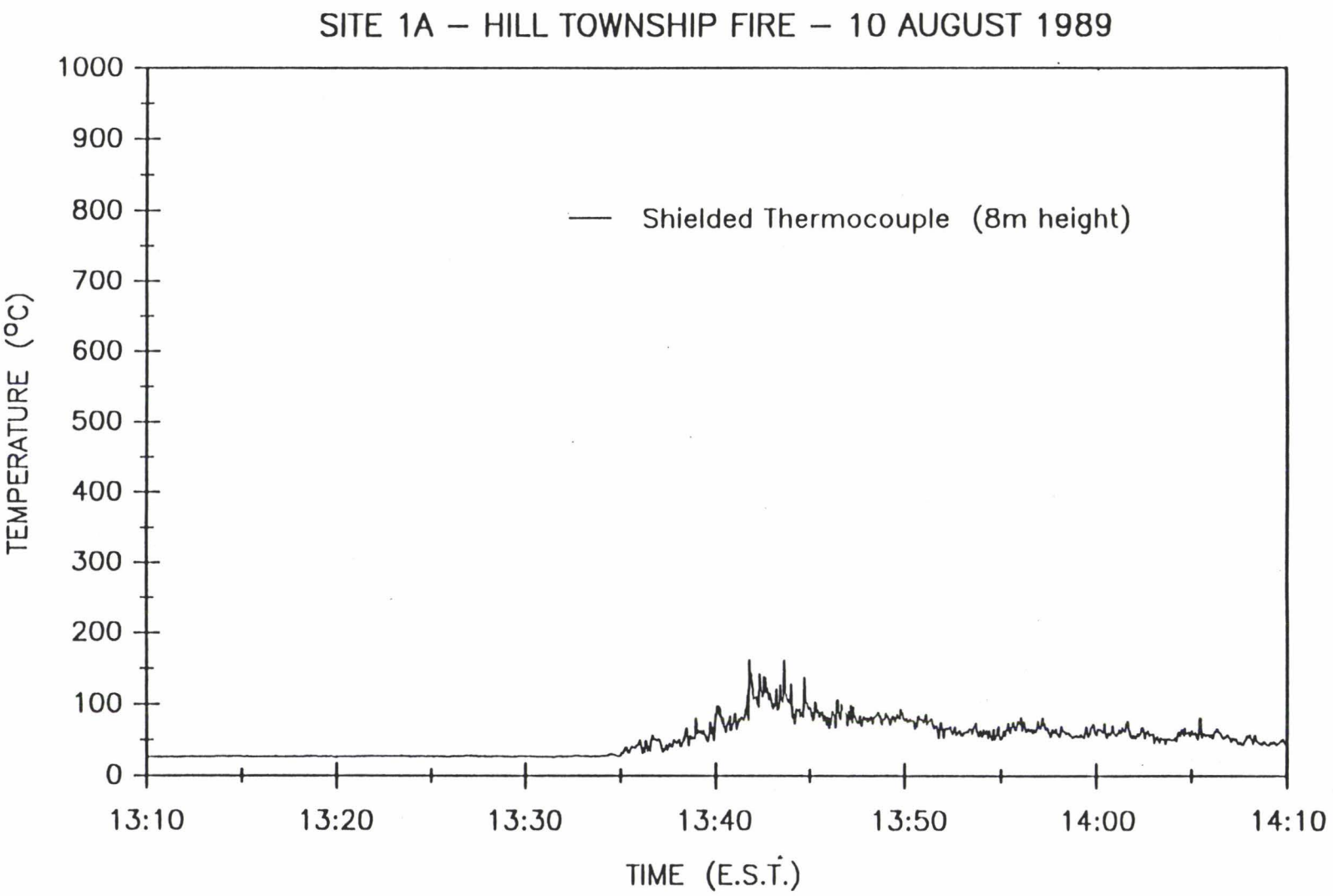


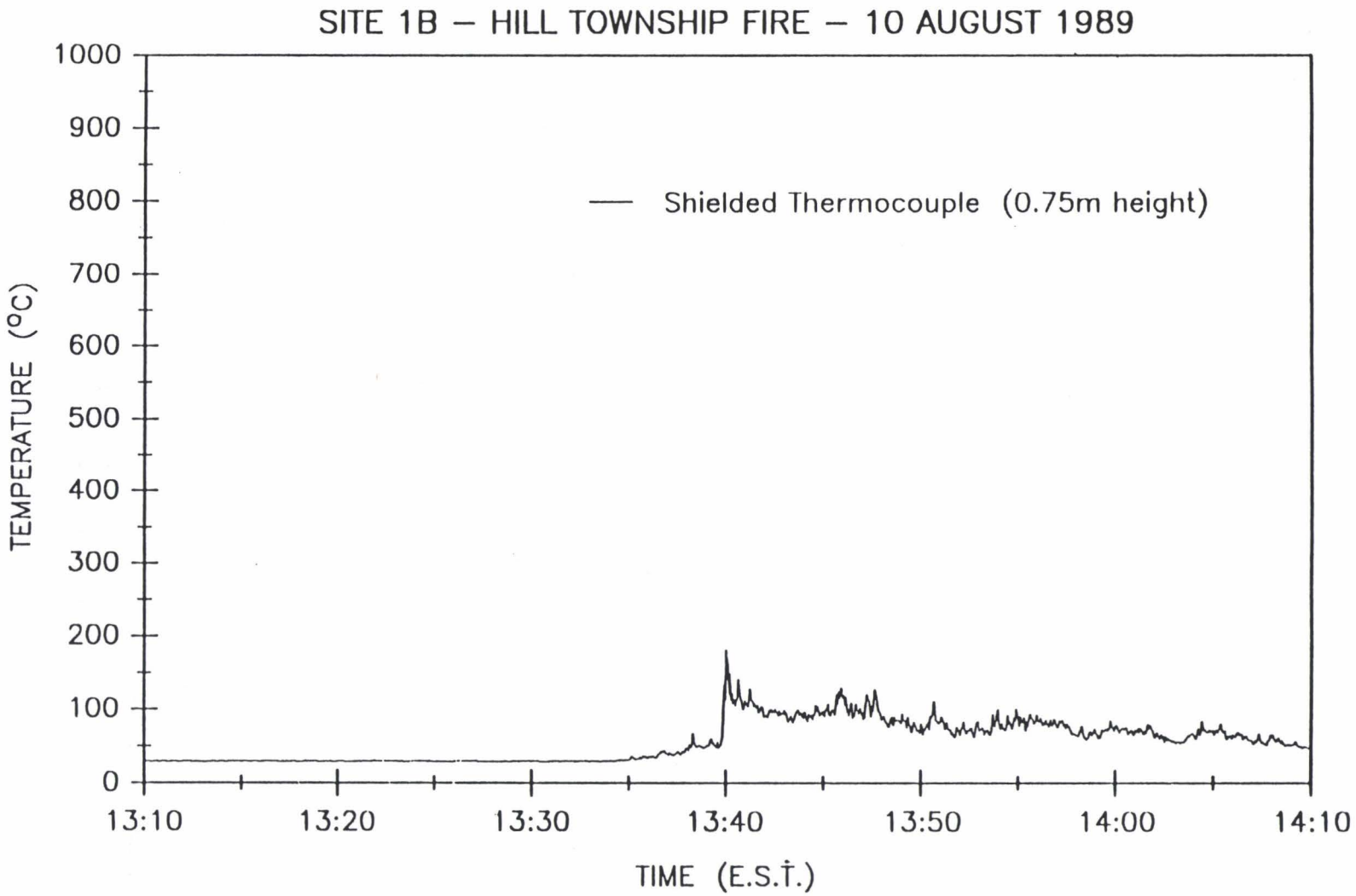

SITE 1A – HILL TOWNSHIP FIRE – 10 AUGUST 1989
Shielded Thermocouple (0.75m height)
TEMPERATURE (°C)
1000
900
800
700
600
500
400
300
200
100
0
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)

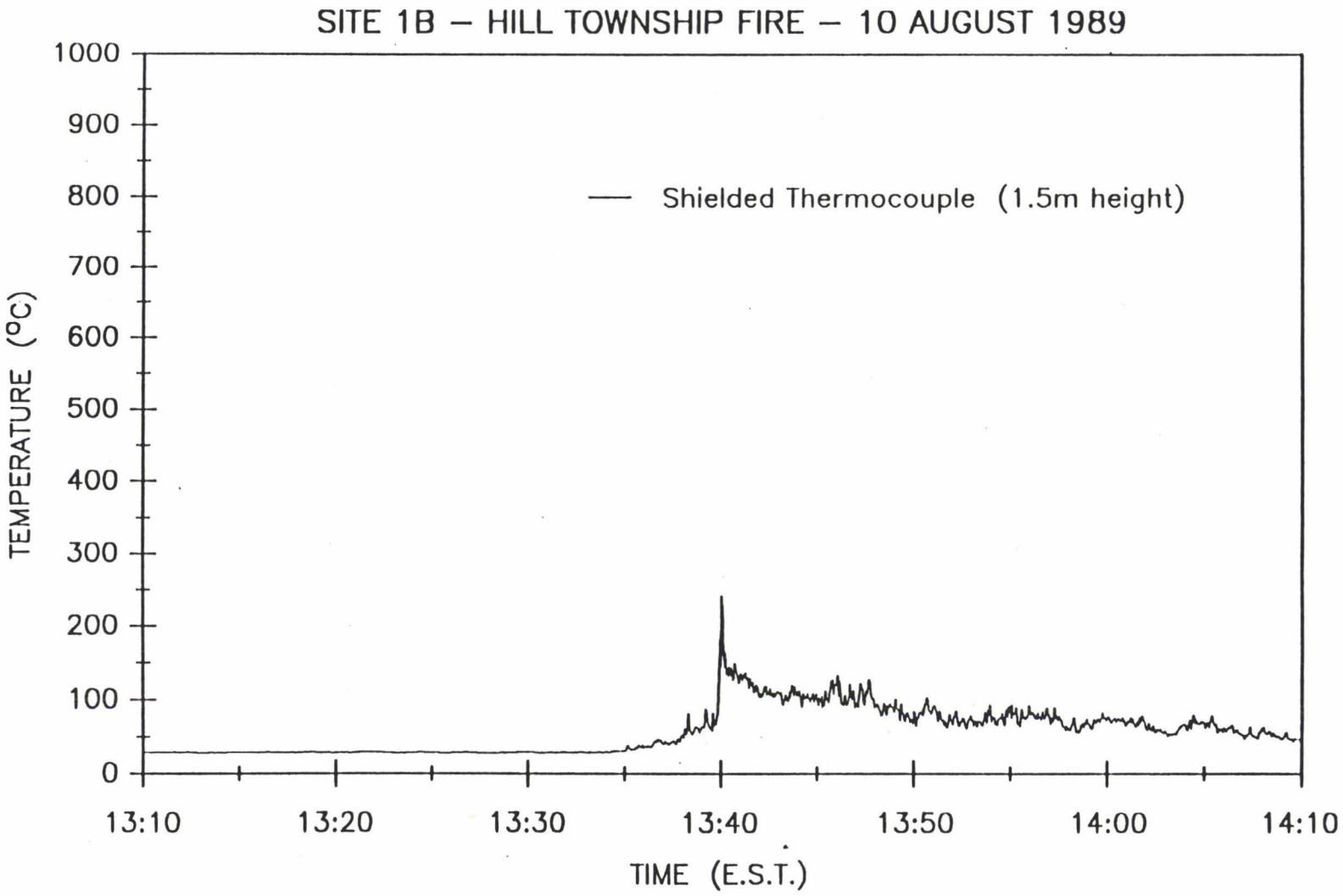

SITE 1A – HILL TOWNSHIP FIRE – 10 AUGUST 1989
1000
900
800
700
600
500
400
300
200
100
0
TEMPERATURE (°C)
Shielded Thermocouple (1.5m height)
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)

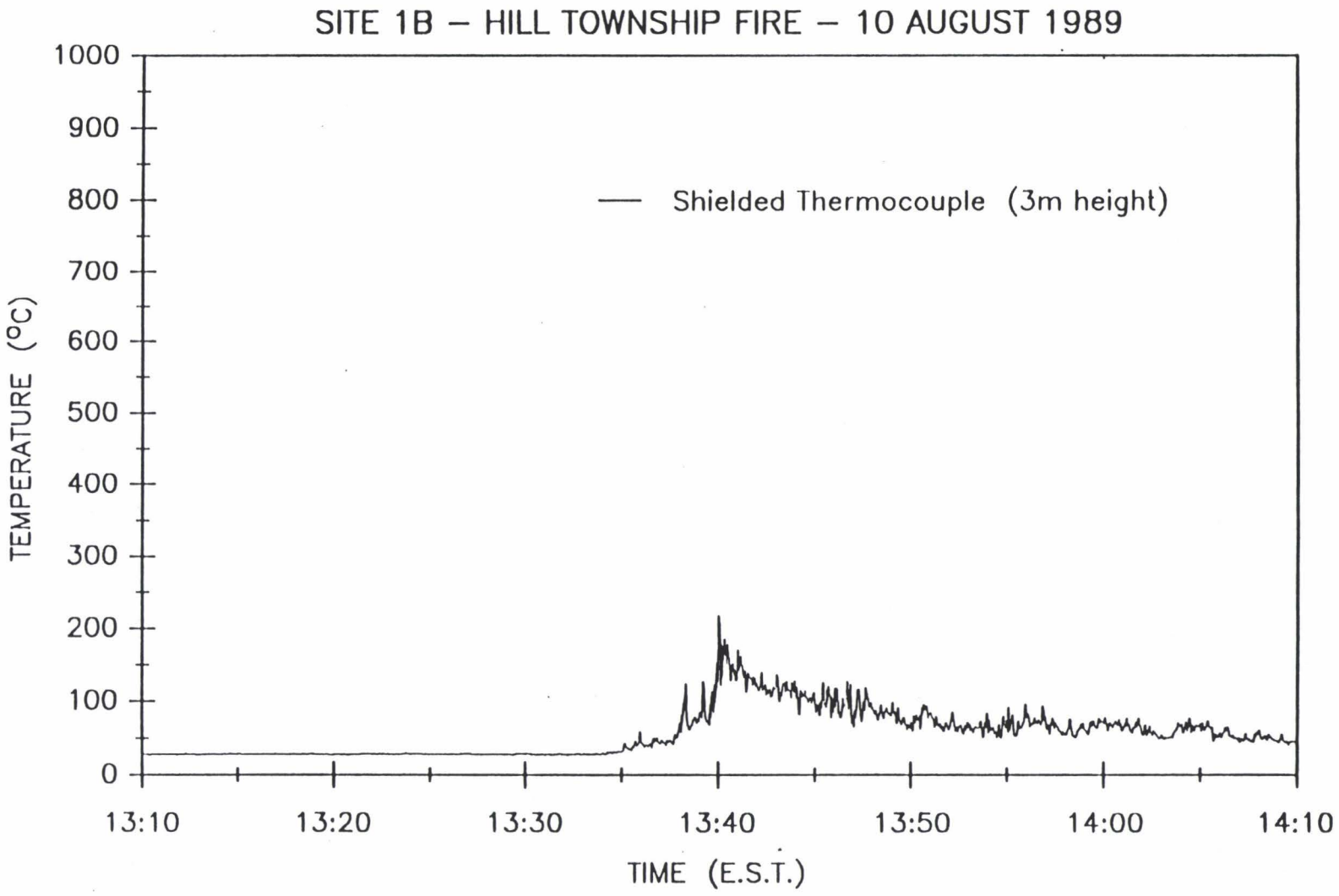

SITE 1A – HILL TOWNSHIP FIRE – 10 AUGUST 1989
Shielded Thermocouple (3m height)
TEMPERATURE (°C)
1000
900
800
700
600
500
400
300
200
100
0
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)

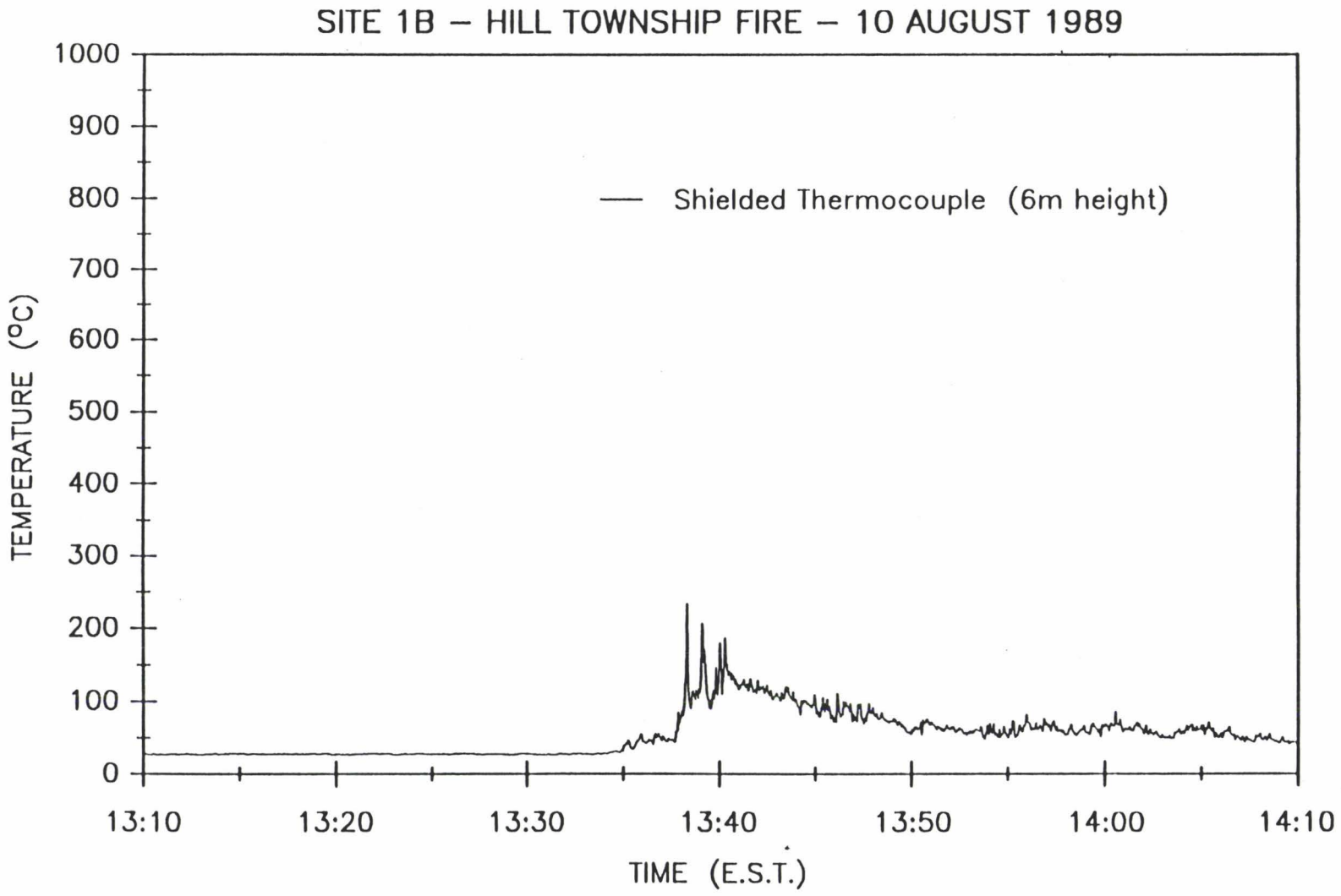

SITE 1A – HILL TOWNSHIP FIRE – 10 AUGUST 1989
Shielded Thermocouple (6m height)
TEMPERATURE (°C)
1000
900
800
700
600
500
400
300
200
100
0
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)

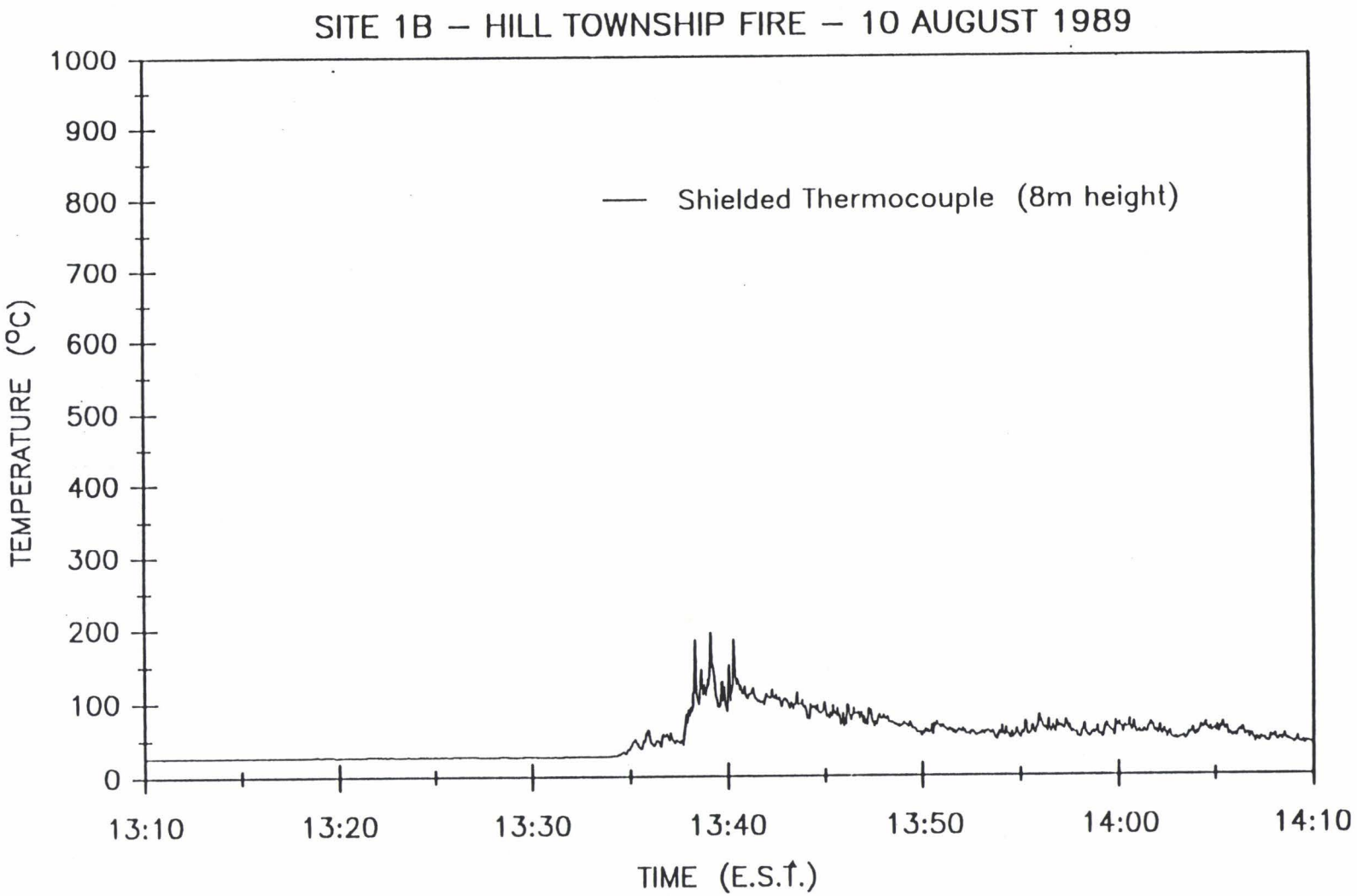

SITE 1A – HILL TOWNSHIP FIRE – 10 AUGUST 1989
1000
900
800
700
600
500
400
300
200
100
0
TEMPERATURE (°C)
Shielded Thermocouple (8m height)
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)

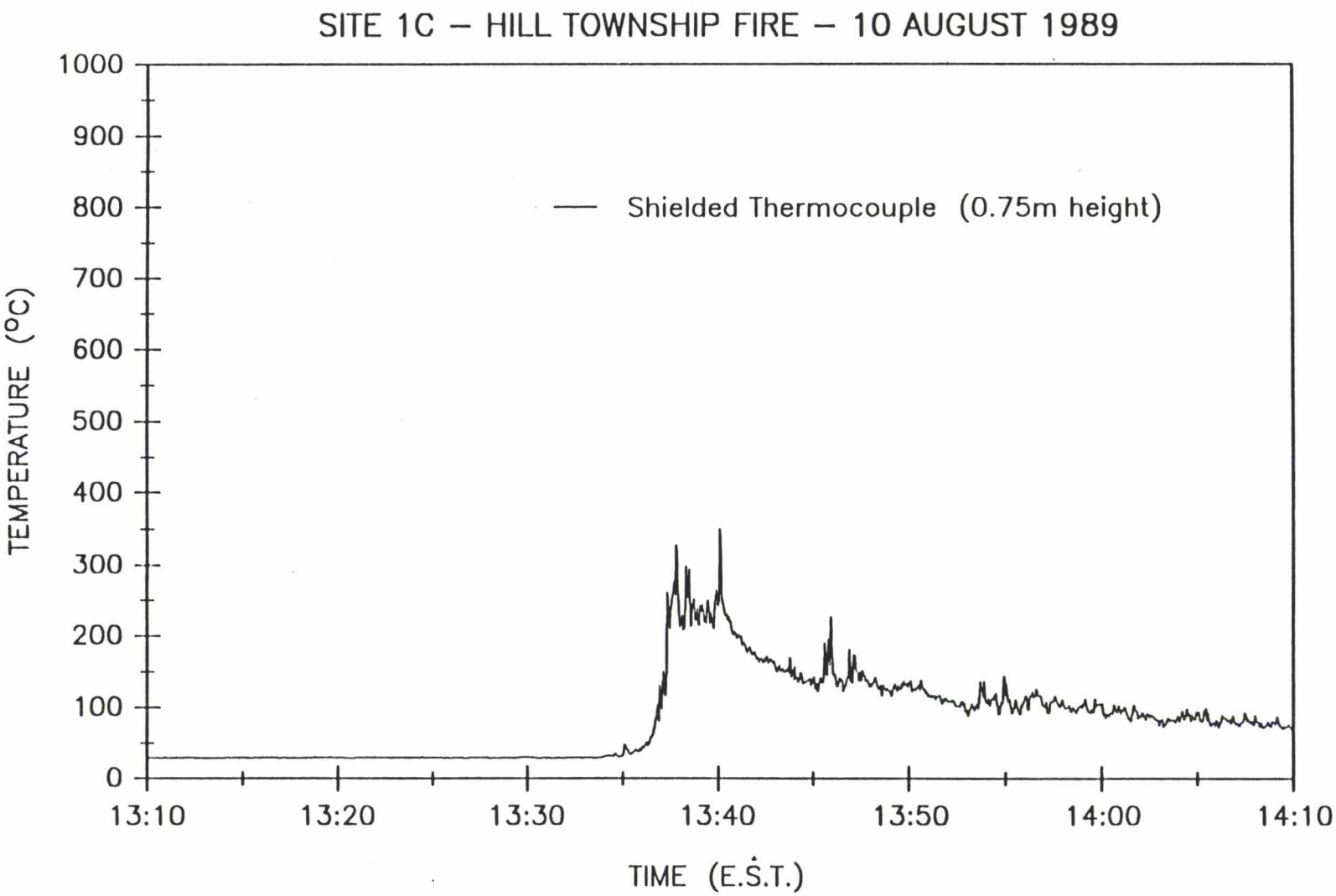

SITE 1B – HILL TOWNSHIP FIRE – 10 AUGUST 1989
Shielded Thermocouple (0.75m height)
TEMPERATURE (°C)
1000
900
800
700
600
500
400
300
200
100
0
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)

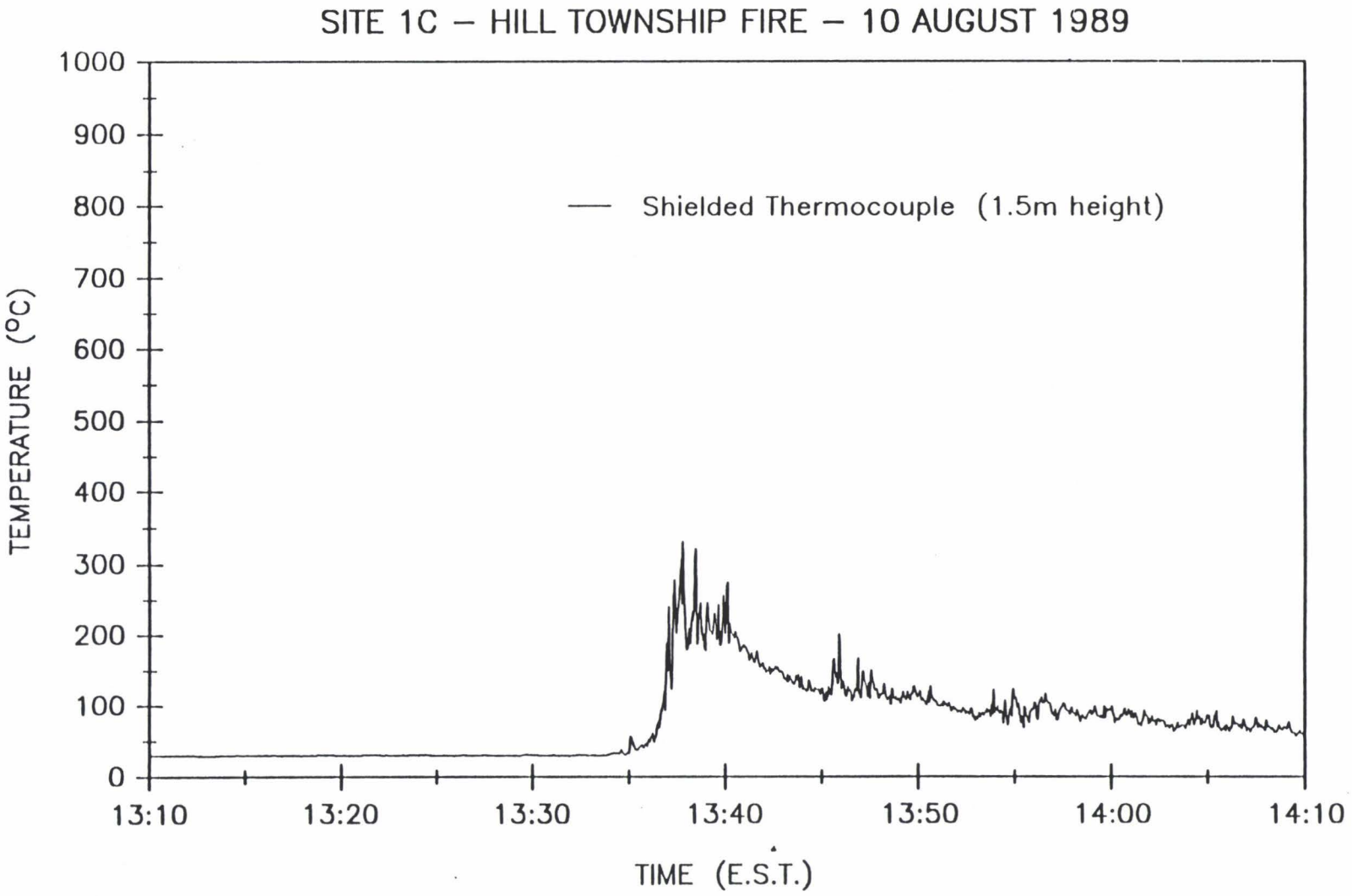

SITE 1B – HILL TOWNSHIP FIRE – 10 AUGUST 1989
Shielded Thermocouple (1.5m height)
TEMPERATURE (°C)
1000
900
800
700
600
500
400
300
200
100
0
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)

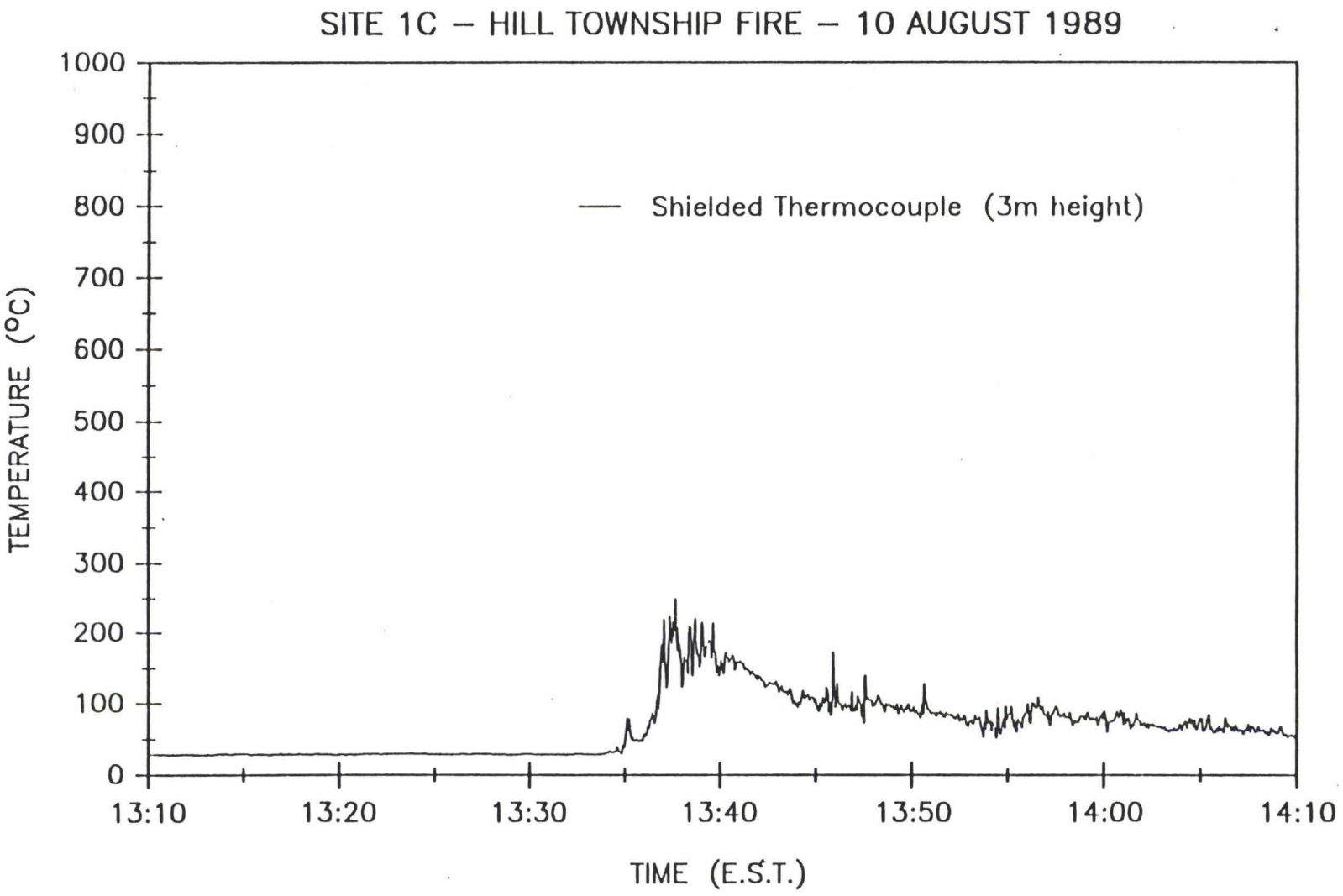

SITE 1B – HILL TOWNSHIP FIRE – 10 AUGUST 1989
Shielded Thermocouple (3m height)
TEMPERATURE (°C)
1000
900
800
700
600
500
400
300
200
100
0
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)

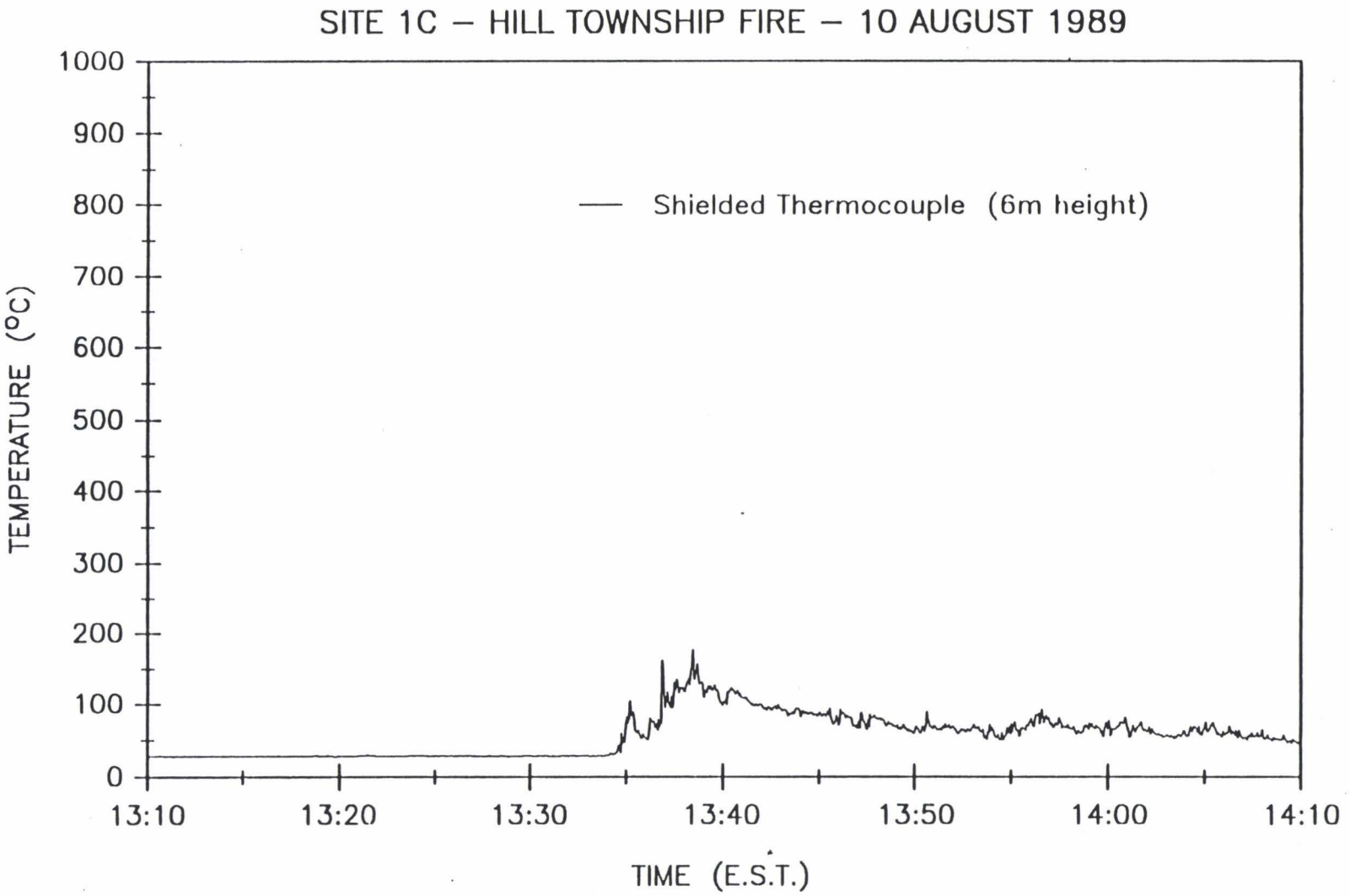

SITE 1B – HILL TOWNSHIP FIRE – 10 AUGUST 1989
1000
900
800
700
600
500
400
300
200
100
0
TEMPERATURE (°C)
Shielded Thermocouple (6m height)
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)

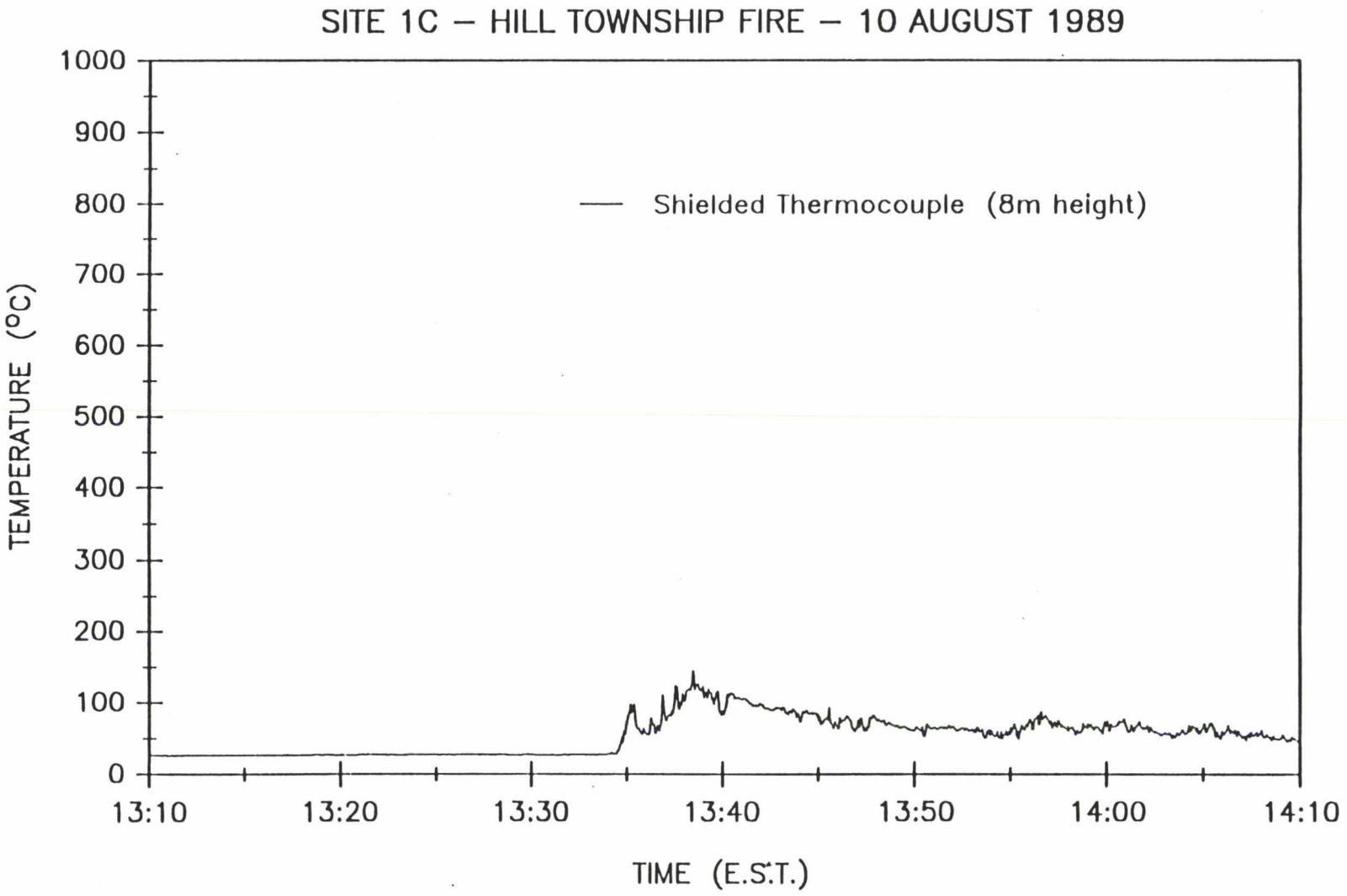

SITE 1B – HILL TOWNSHIP FIRE – 10 AUGUST 1989
Shielded Thermocouple (8m height)
TEMPERATURE (°C)
1000
900
800
700
600
500
400
300
200
100
0
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)

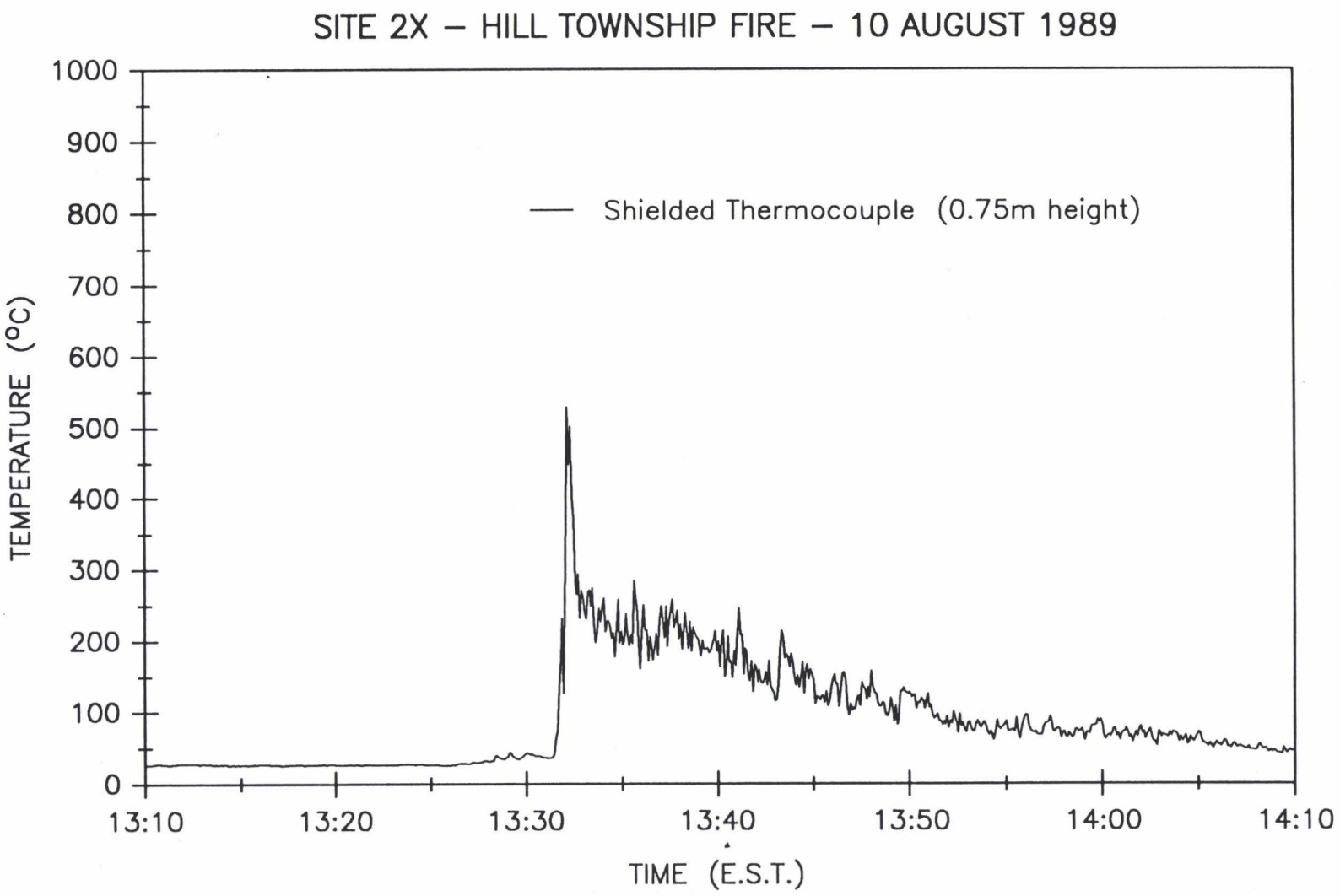

SITE 1C – HILL TOWNSHIP FIRE – 10 AUGUST 1989
Shielded Thermocouple (0.75m height)
TEMPERATURE (°C)
1000
900
800
700
600
500
400
300
200
100
0
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)

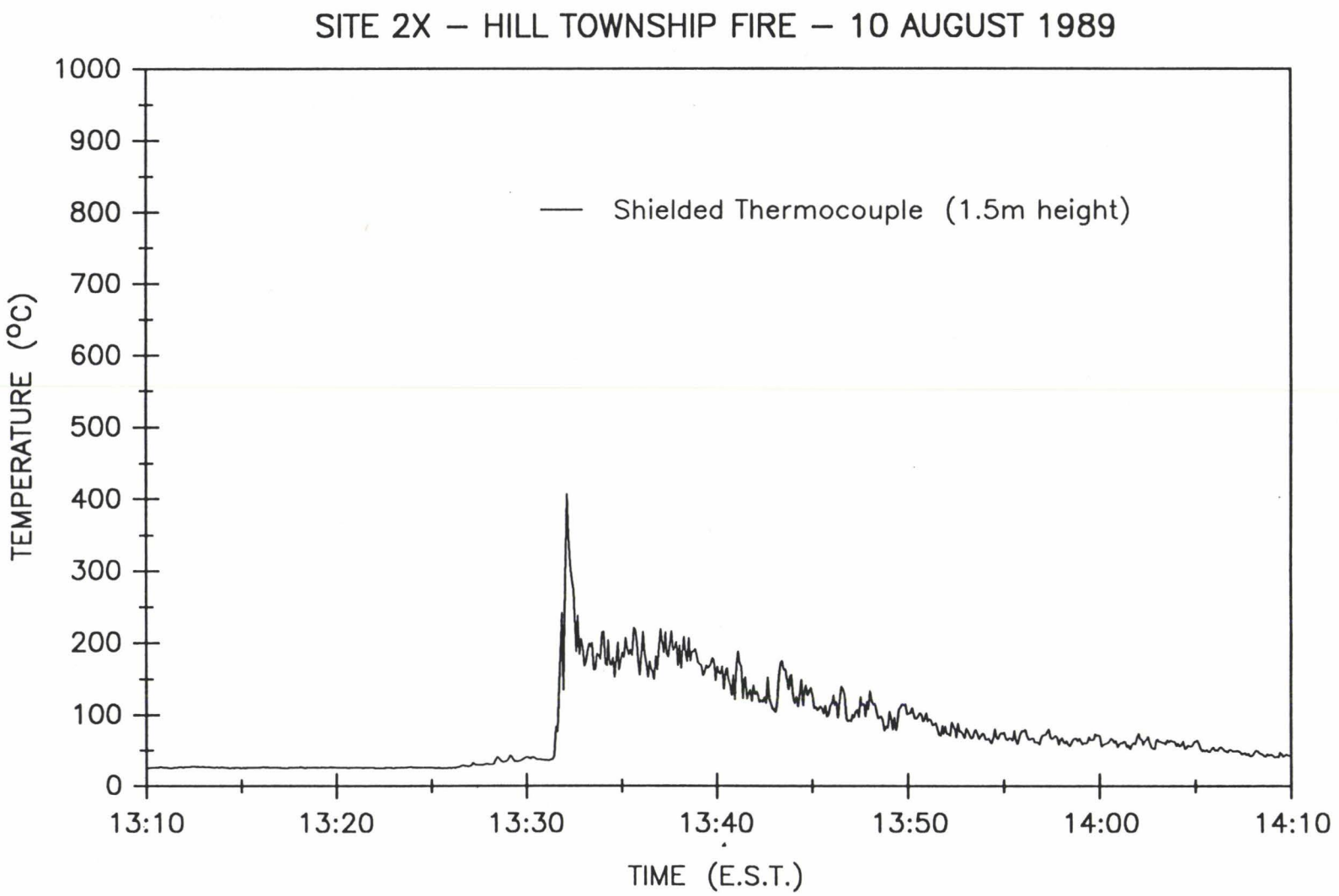

SITE 1C – HILL TOWNSHIP FIRE – 10 AUGUST 1989
1000
900
800
700
600
500
400
300
200
100
0
TEMPERATURE (°C)
Shielded Thermocouple (1.5m height)
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)

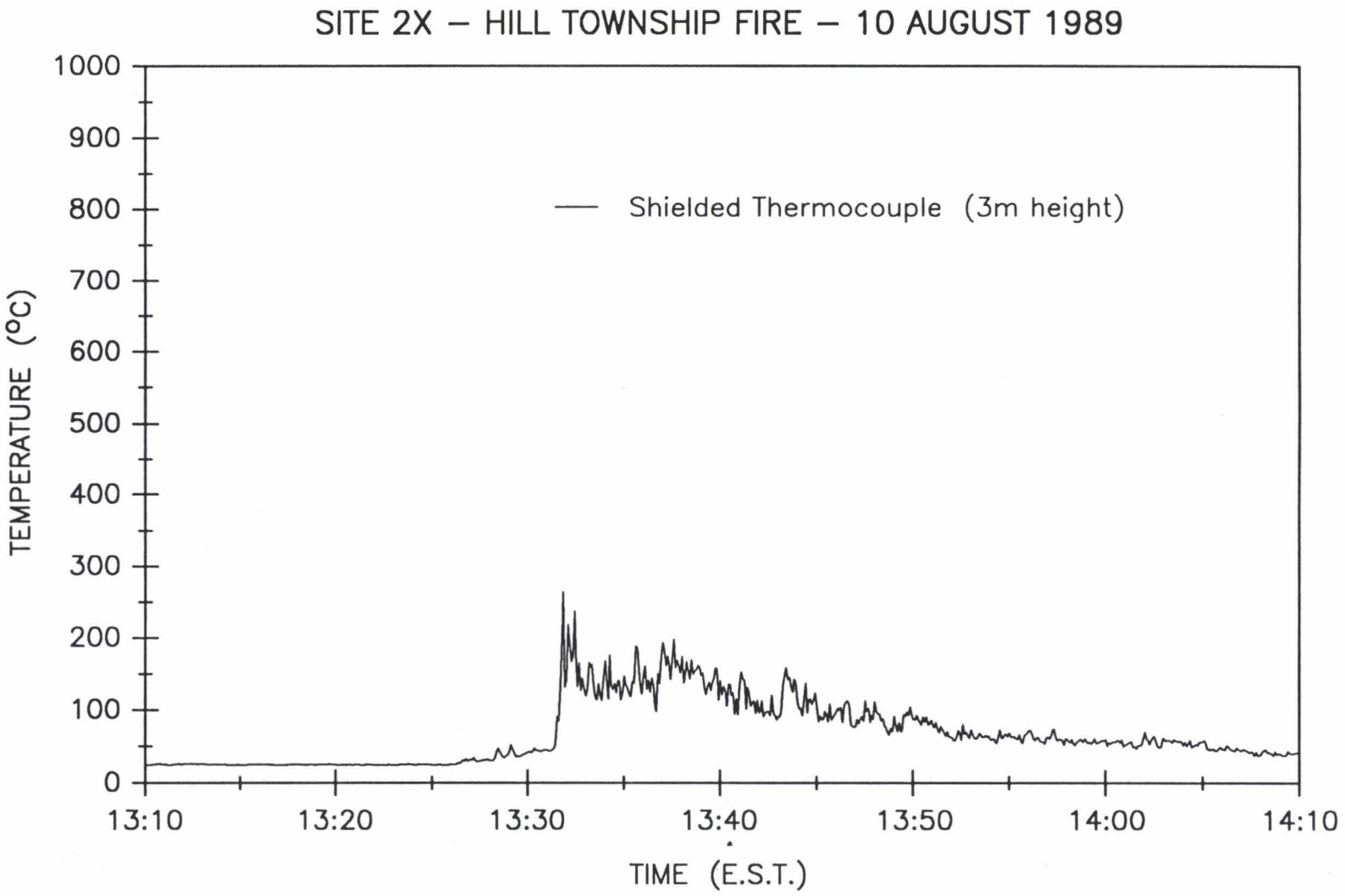

SITE 1C – HILL TOWNSHIP FIRE – 10 AUGUST 1989
Shielded Thermocouple (3m height)
TEMPERATURE (°C)
1000
900
800
700
600
500
400
300
200
100
0
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)

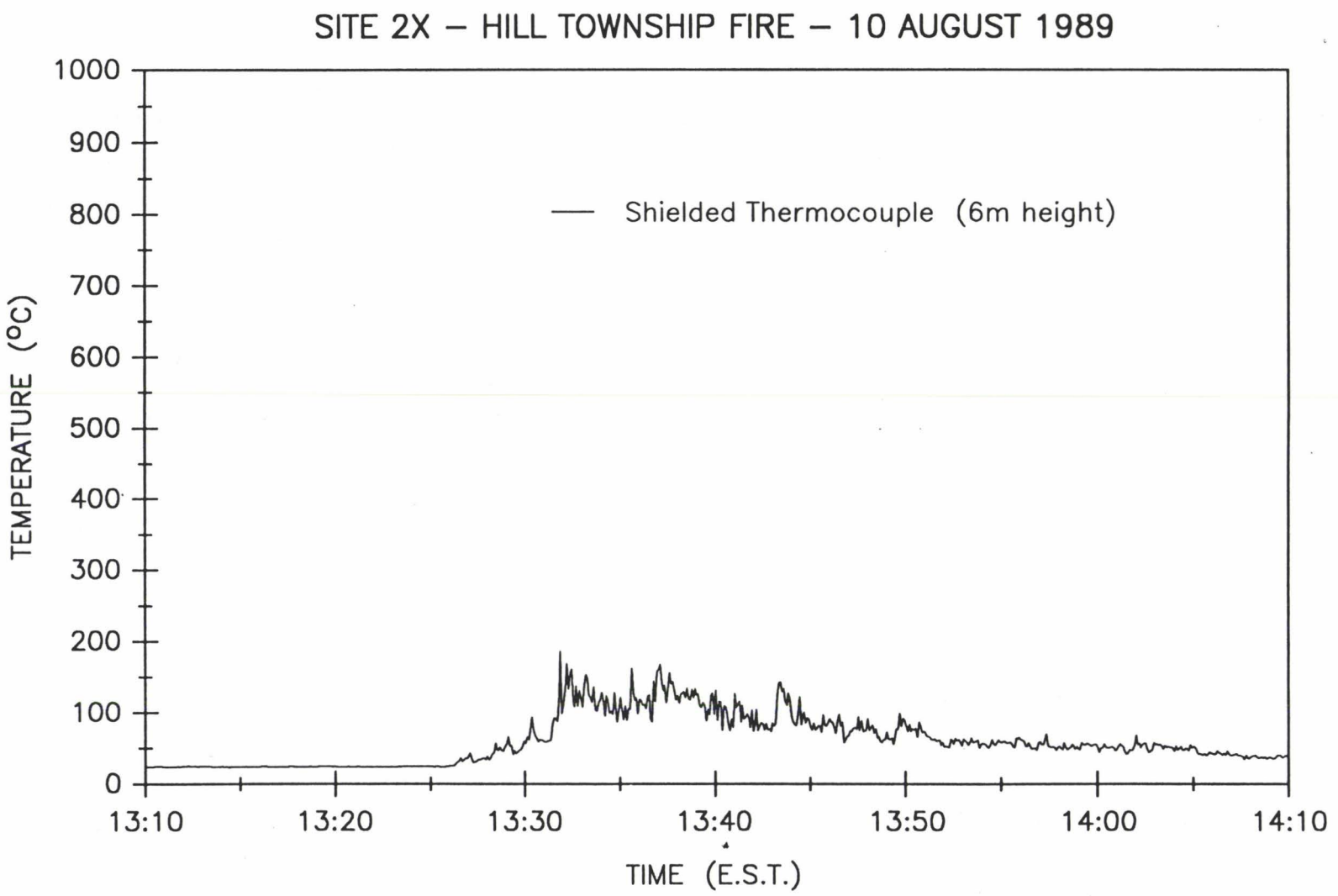

SITE 1C – HILL TOWNSHIP FIRE – 10 AUGUST 1989
Shielded Thermocouple (6m height)
TEMPERATURE (°C)
1000
900
800
700
600
500
400
300
200
100
0
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)

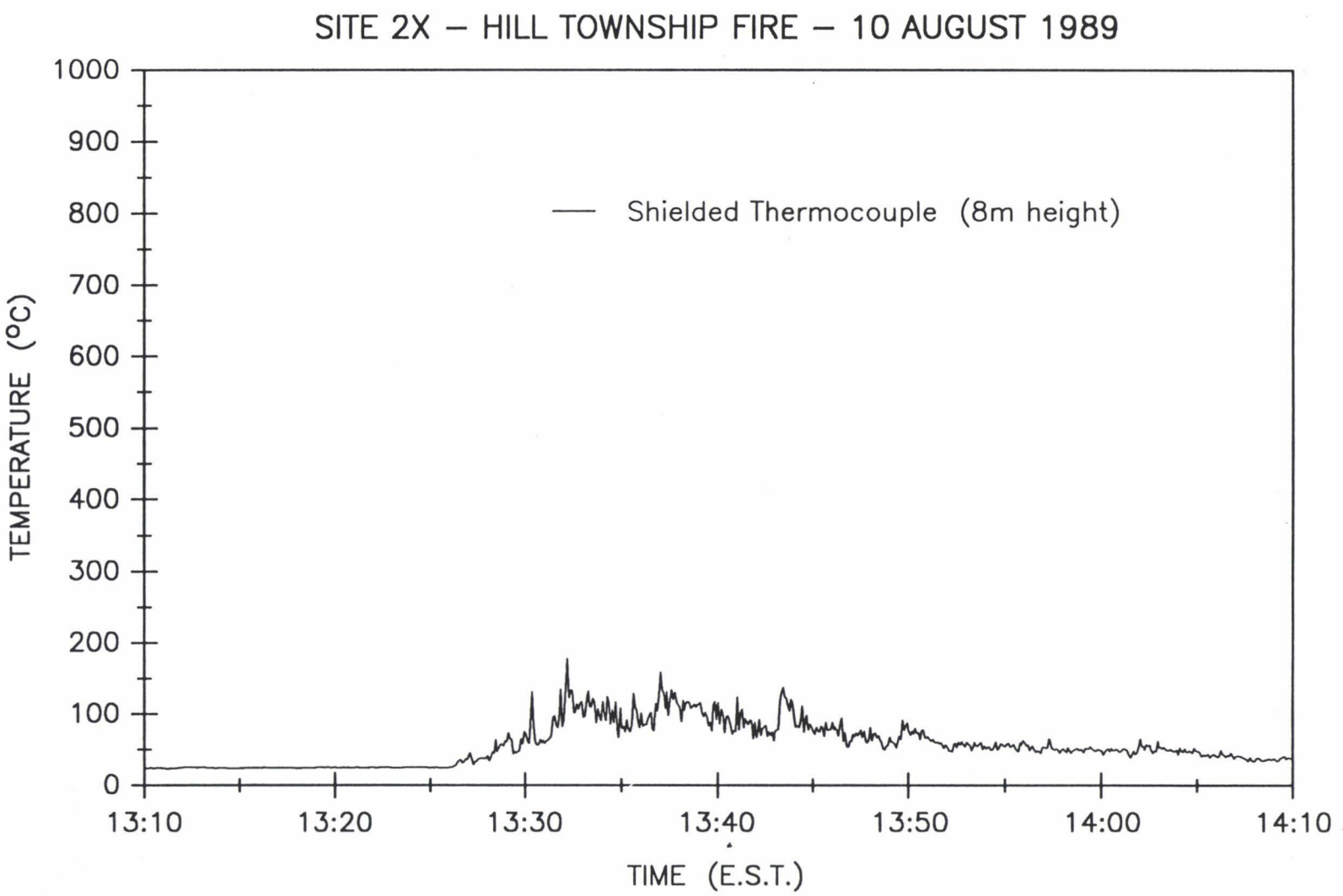

SITE 1C – HILL TOWNSHIP FIRE – 10 AUGUST 1989
Shielded Thermocouple (8m height)
TEMPERATURE (°C)
1000
900
800
700
600
500
400
300
200
100
0
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)

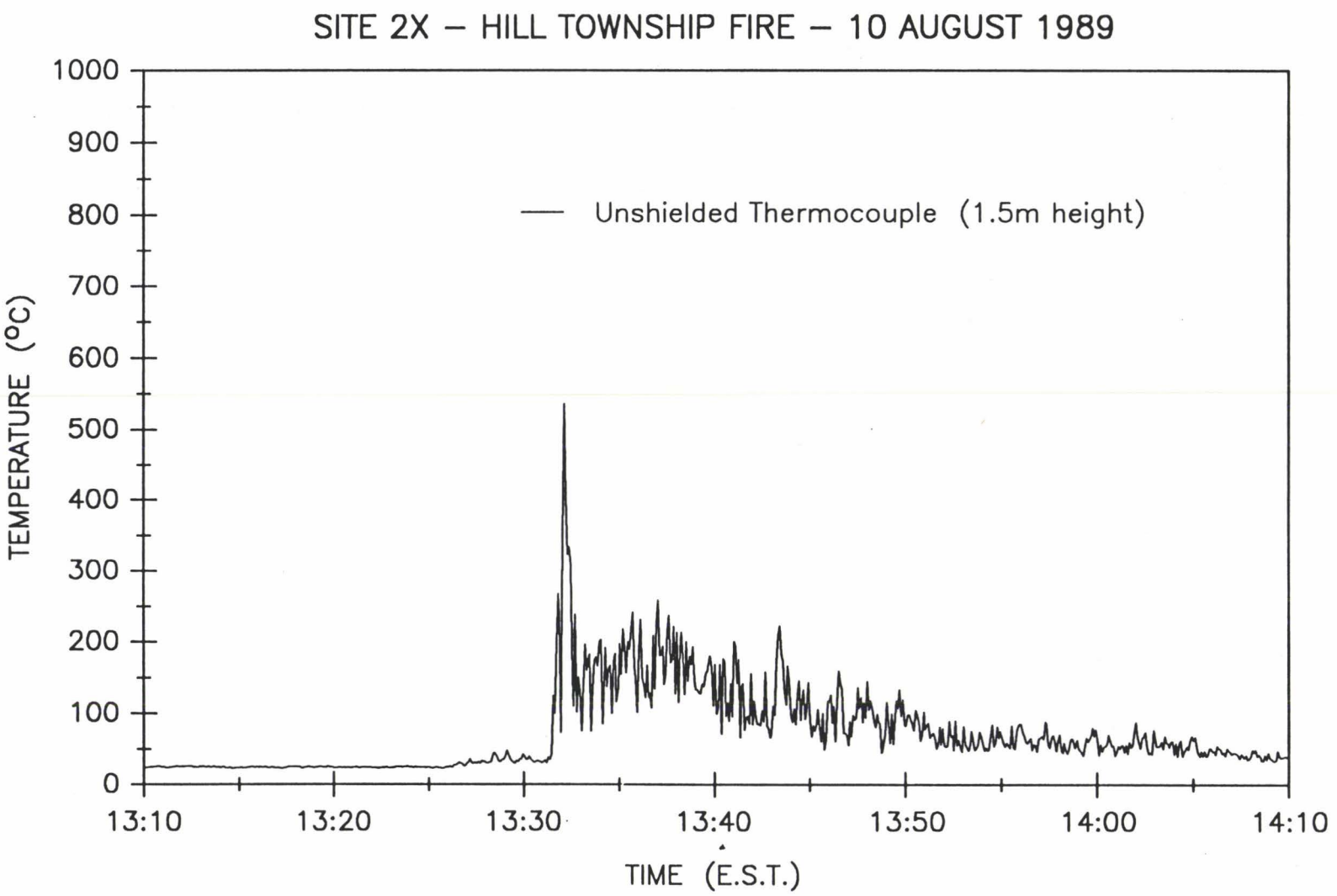

SITE 2X – HILL TOWNSHIP FIRE – 10 AUGUST 1989
Shielded Thermocouple (0.75m height)
TEMPERATURE (°C)
1000
900
800
700
600
500
400
300
200
100
0
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)

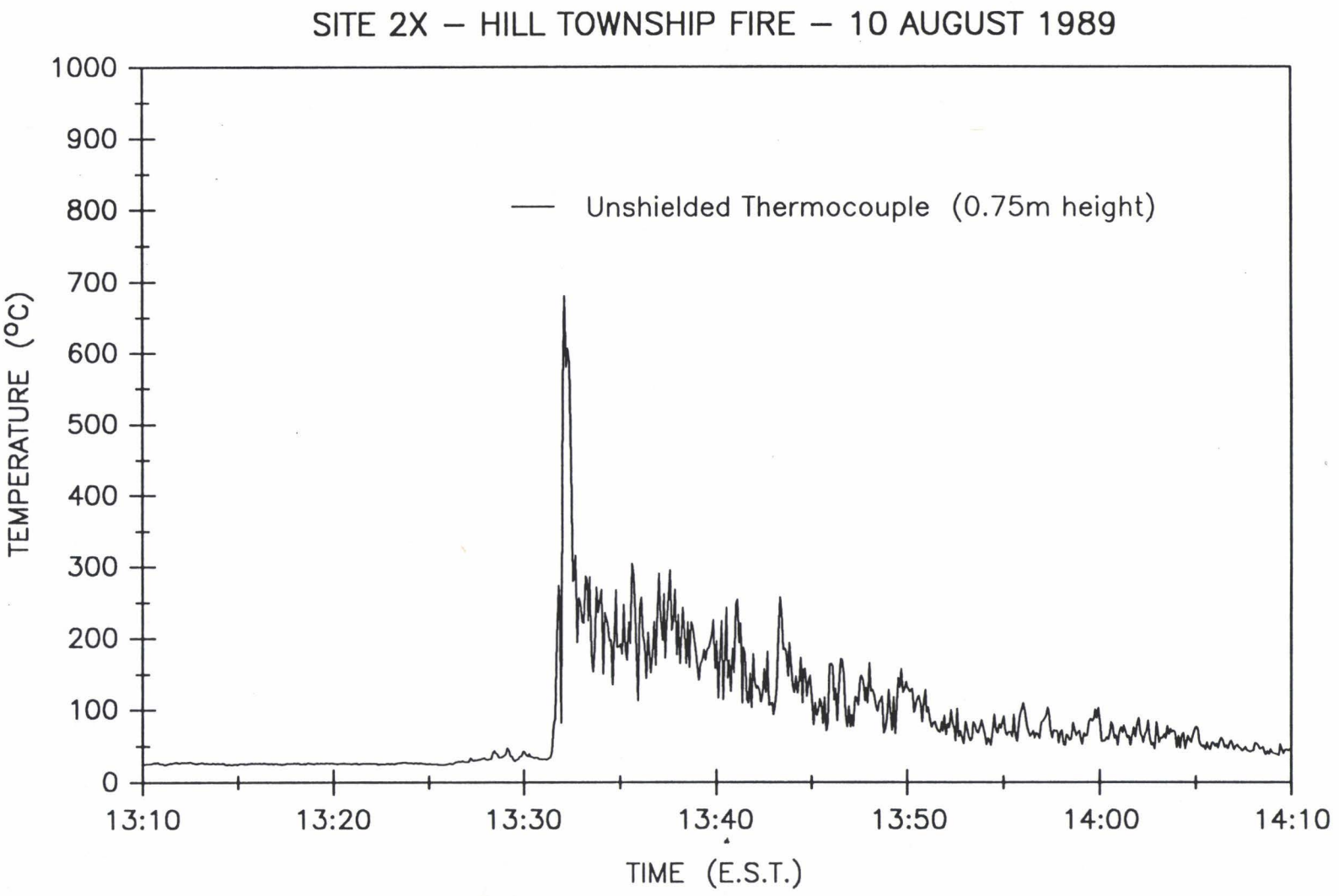

SITE 2X – HILL TOWNSHIP FIRE – 10 AUGUST 1989
Shielded Thermocouple (1.5m height)
TEMPERATURE (°C)
1000
900
800
700
600
500
400
300
200
100
0
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)

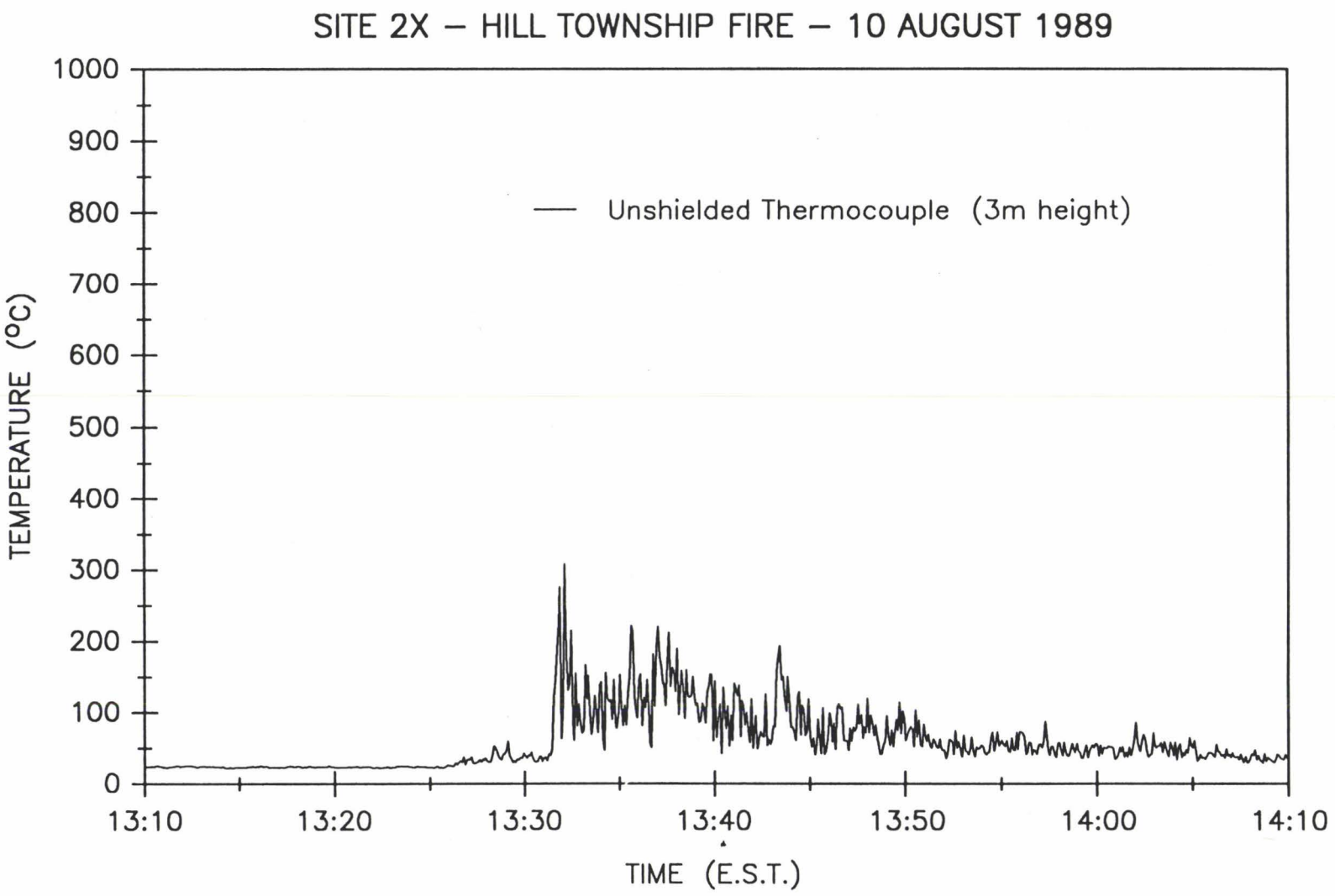

SITE 2X – HILL TOWNSHIP FIRE – 10 AUGUST 1989
1000
900
800
700
600
500
400
300
200
100
0
TEMPERATURE (°C)
Shielded Thermocouple (3m height)
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)

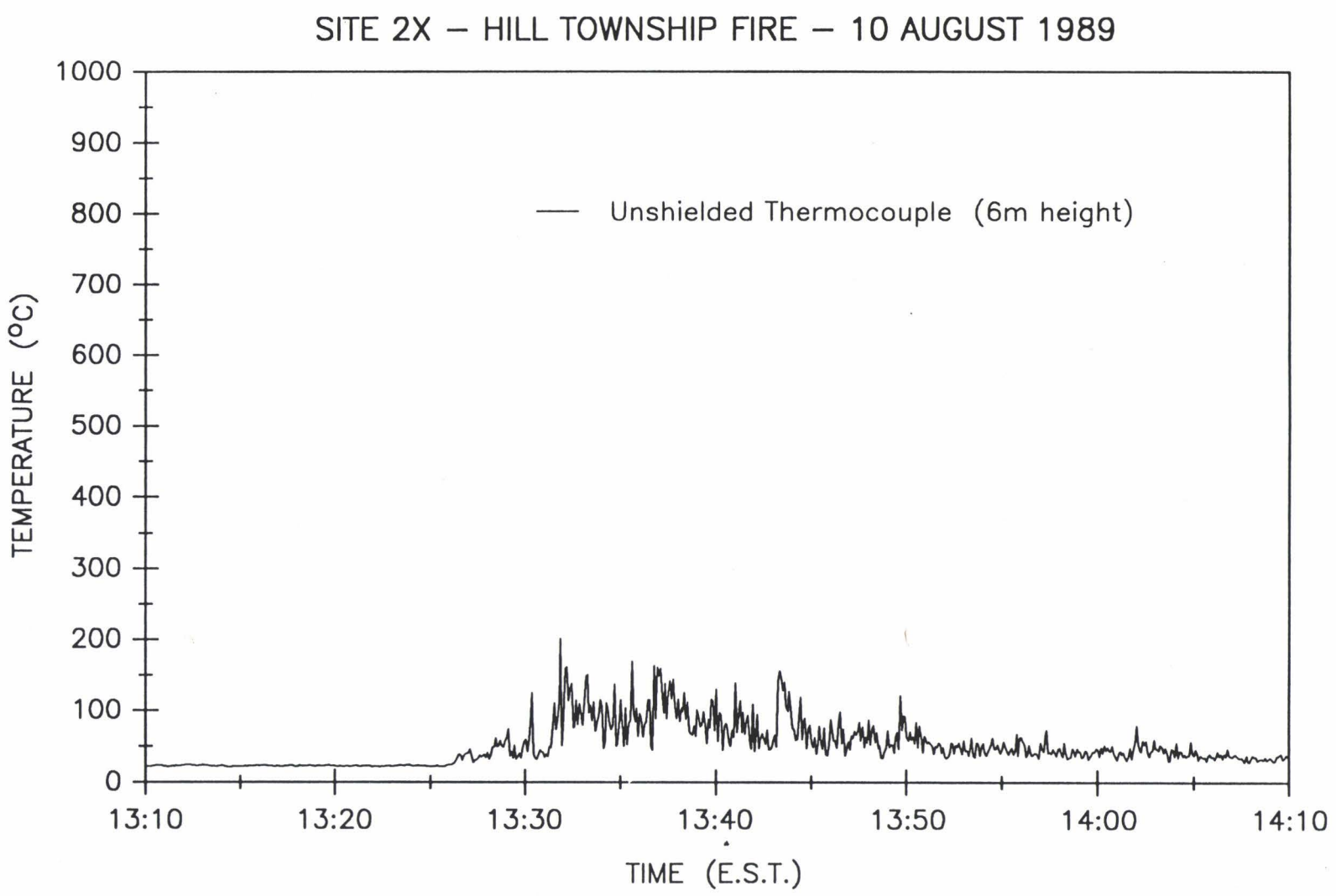

SITE 2X – HILL TOWNSHIP FIRE – 10 AUGUST 1989
Shielded Thermocouple (6m height)
TEMPERATURE (°C)
1000
900
800
700
600
500
400
300
200
100
0
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)

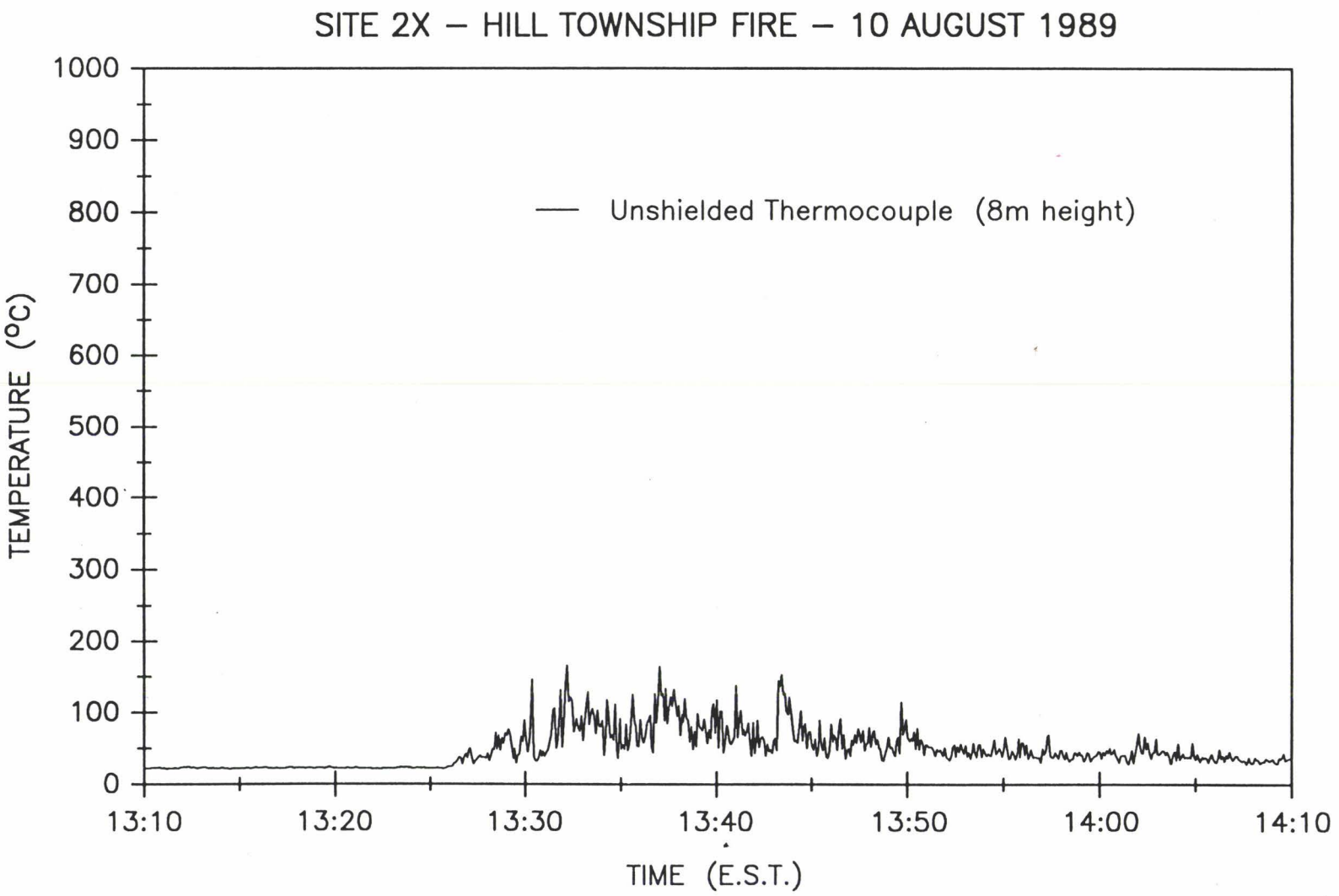

SITE 2X – HILL TOWNSHIP FIRE – 10 AUGUST 1989
Shielded Thermocouple (8m height)
TEMPERATURE (°C)
1000
900
800
700
600
500
400
300
200
100
0
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)

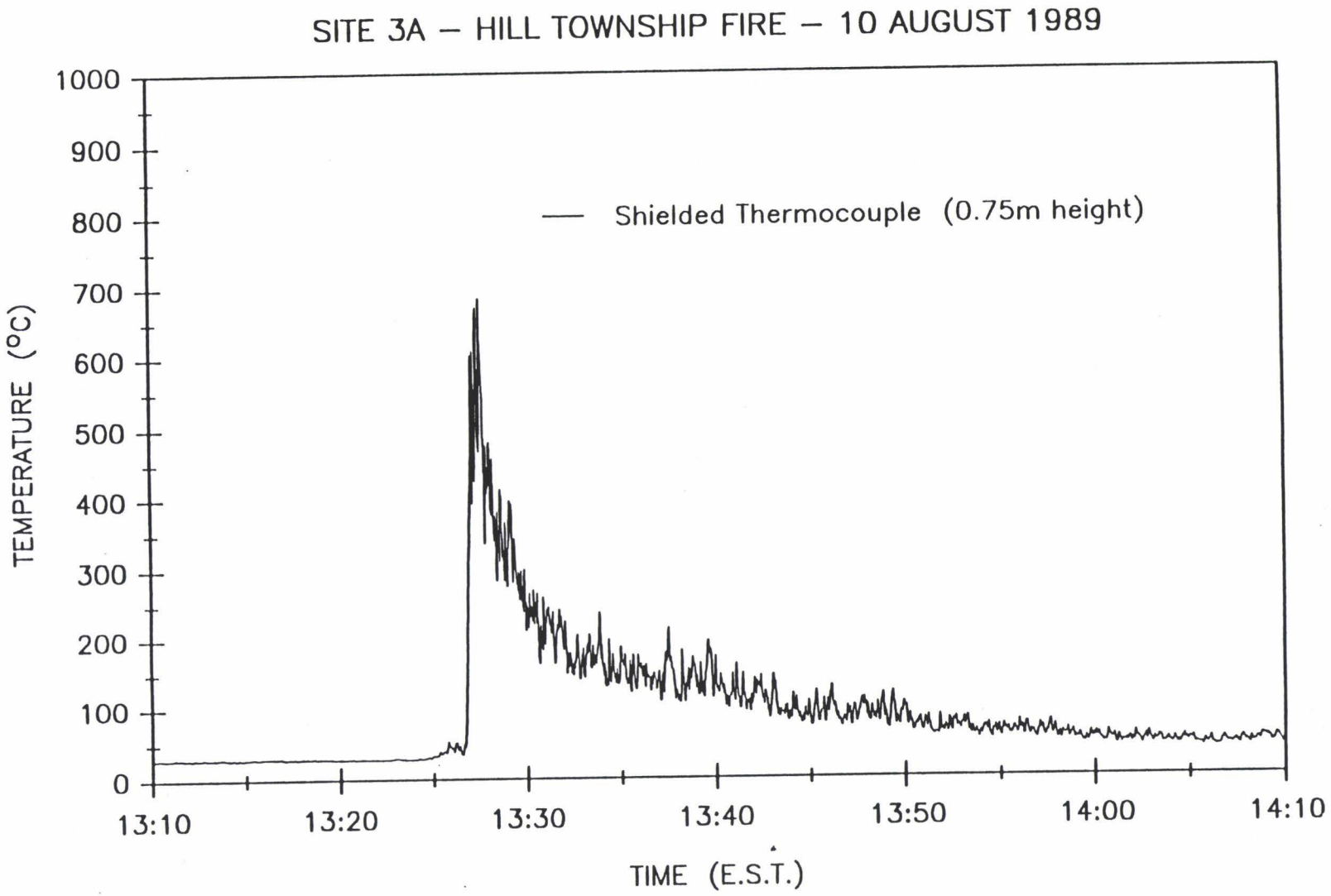

SITE 2X – HILL TOWNSHIP FIRE – 10 AUGUST 1989
Unshielded Thermocouple (1.5m height)
TEMPERATURE (°C)
1000
900
800
700
600
500
400
300
200
100
0
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)

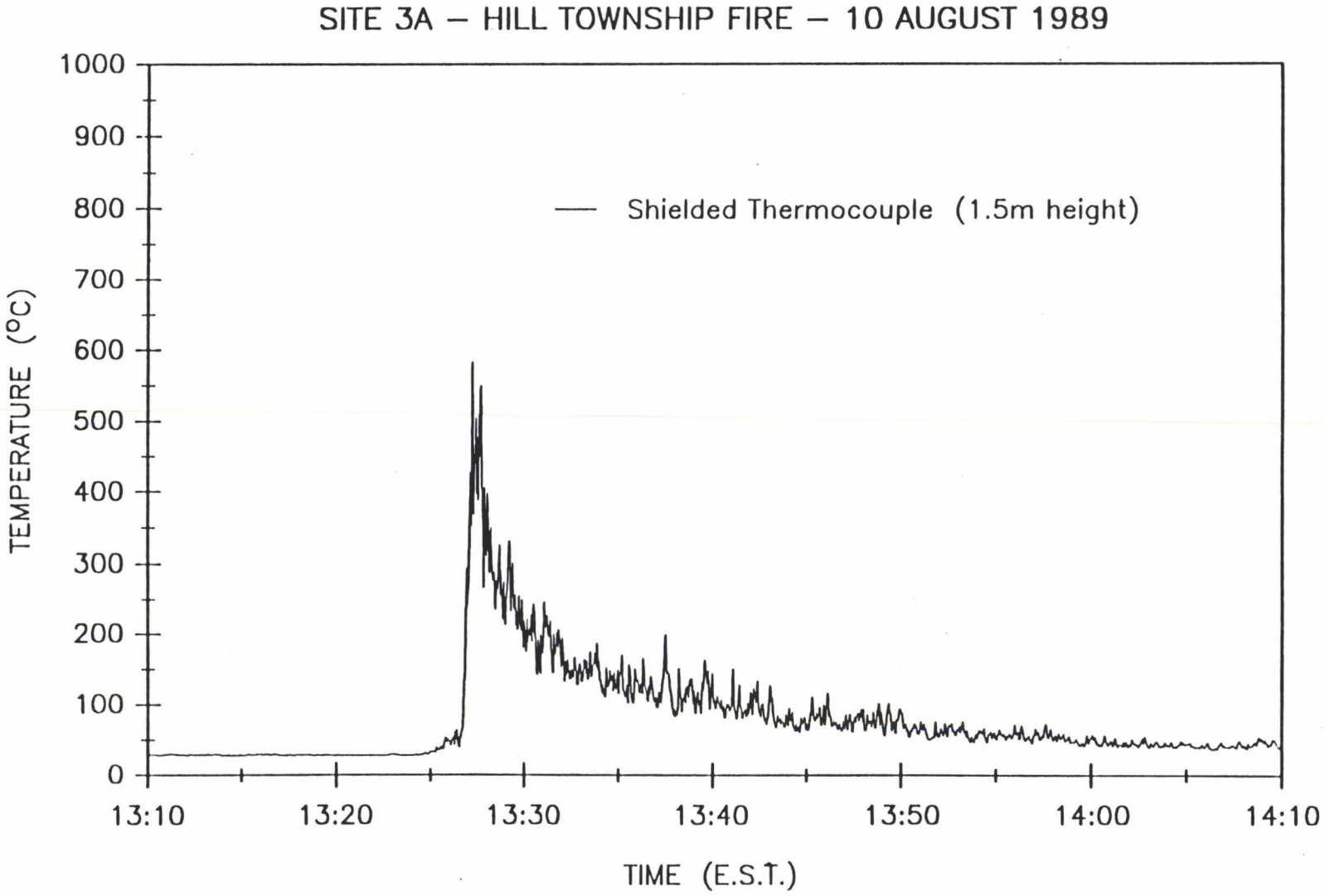

SITE 2X – HILL TOWNSHIP FIRE – 10 AUGUST 1989
Unshielded Thermocouple (0.75m height)
TEMPERATURE (°C)
1000
900
800
700
600
500
400
300
200
100
0
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)

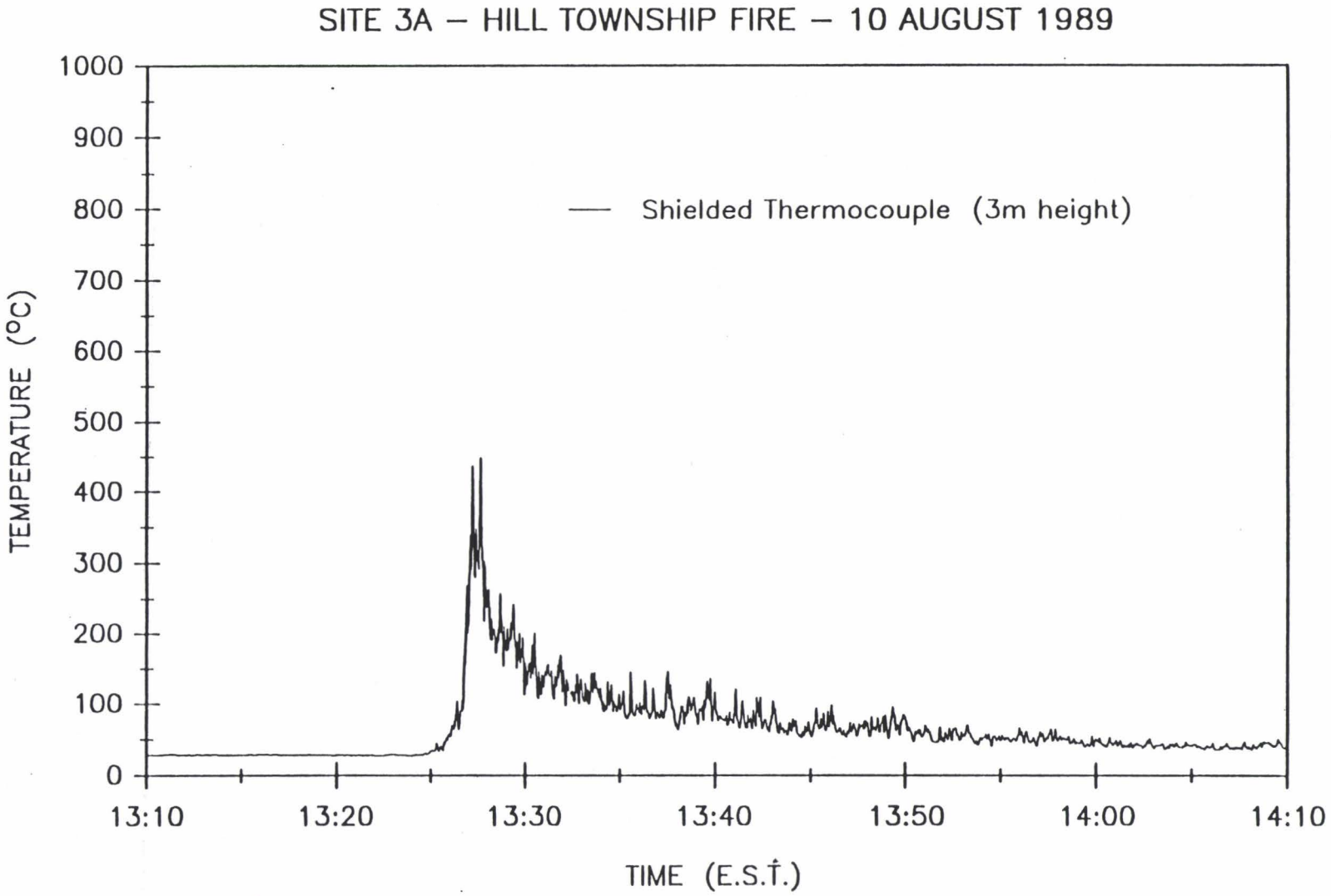

SITE 2X – HILL TOWNSHIP FIRE – 10 AUGUST 1989
Unshielded Thermocouple (3m height)
TEMPERATURE (°C)
1000
900
800
700
600
500
400
300
200
100
0
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)

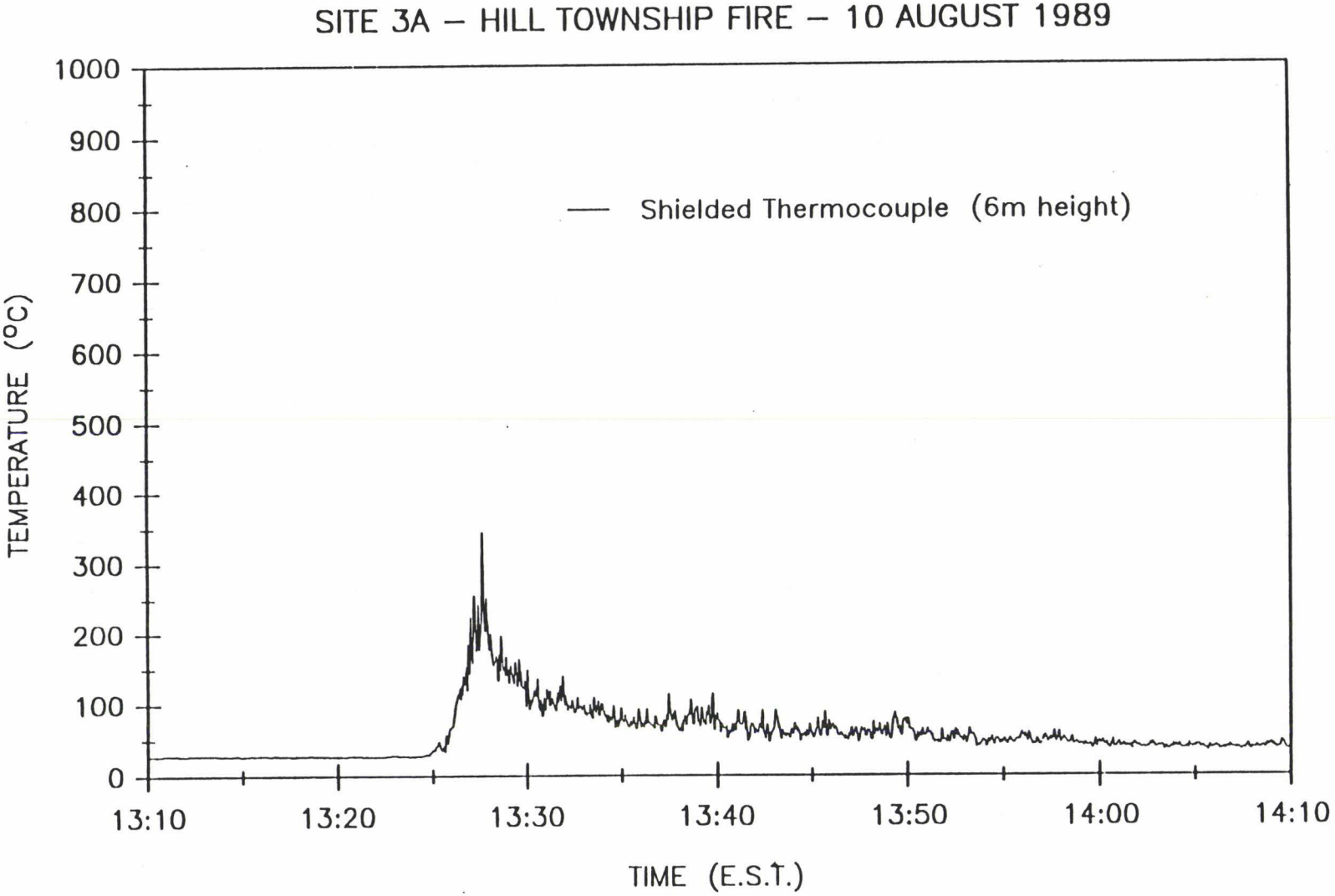

SITE 2X – HILL TOWNSHIP FIRE – 10 AUGUST 1989
Unshielded Thermocouple (6m height)
TEMPERATURE (°C)
1000
900
800
700
600
500
400
300
200
100
0
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)

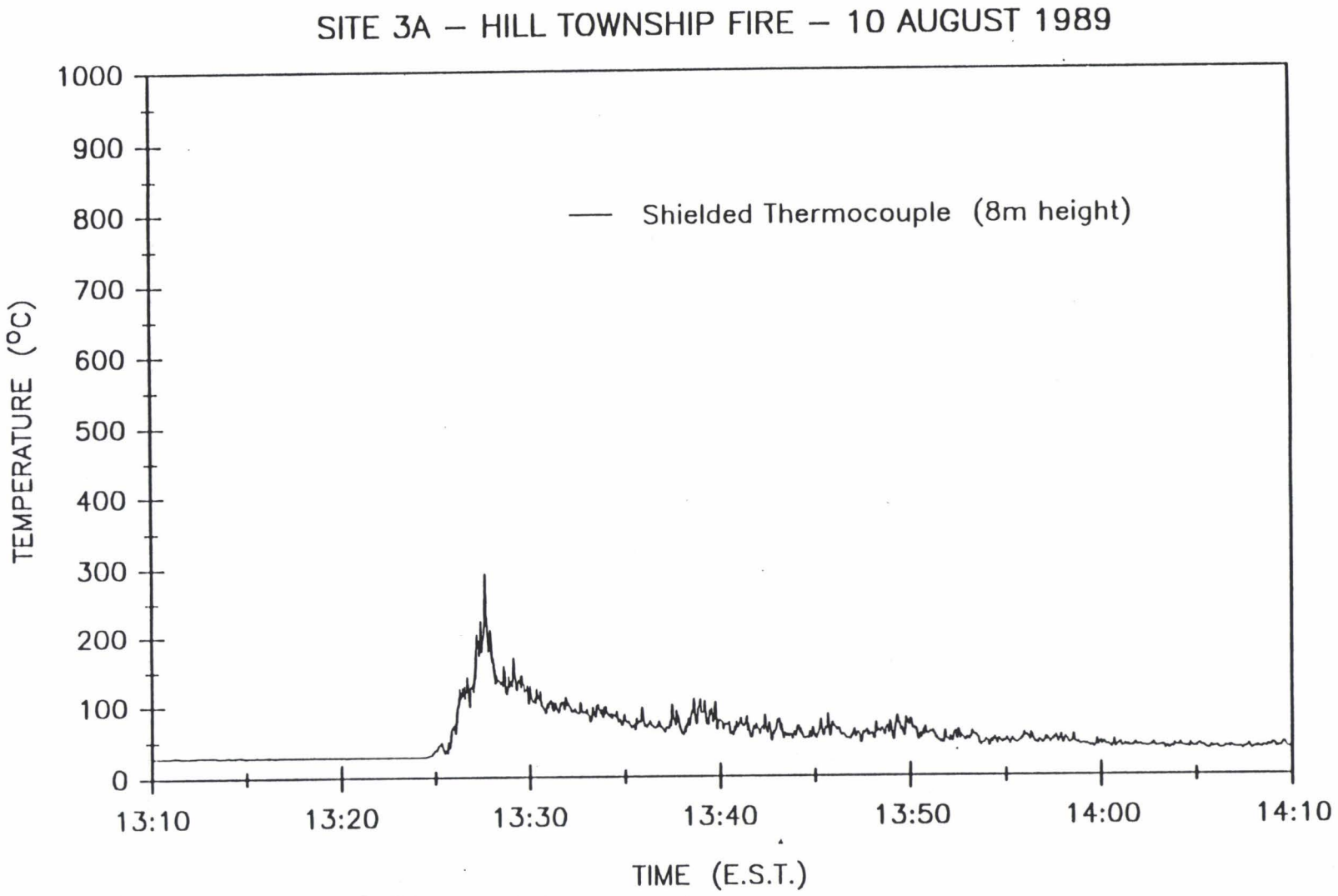

SITE 2X – HILL TOWNSHIP FIRE – 10 AUGUST 1989
Unshielded Thermocouple (8m height)
TEMPERATURE (°C)
1000
900
800
700
600
500
400
300
200
100
0
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)

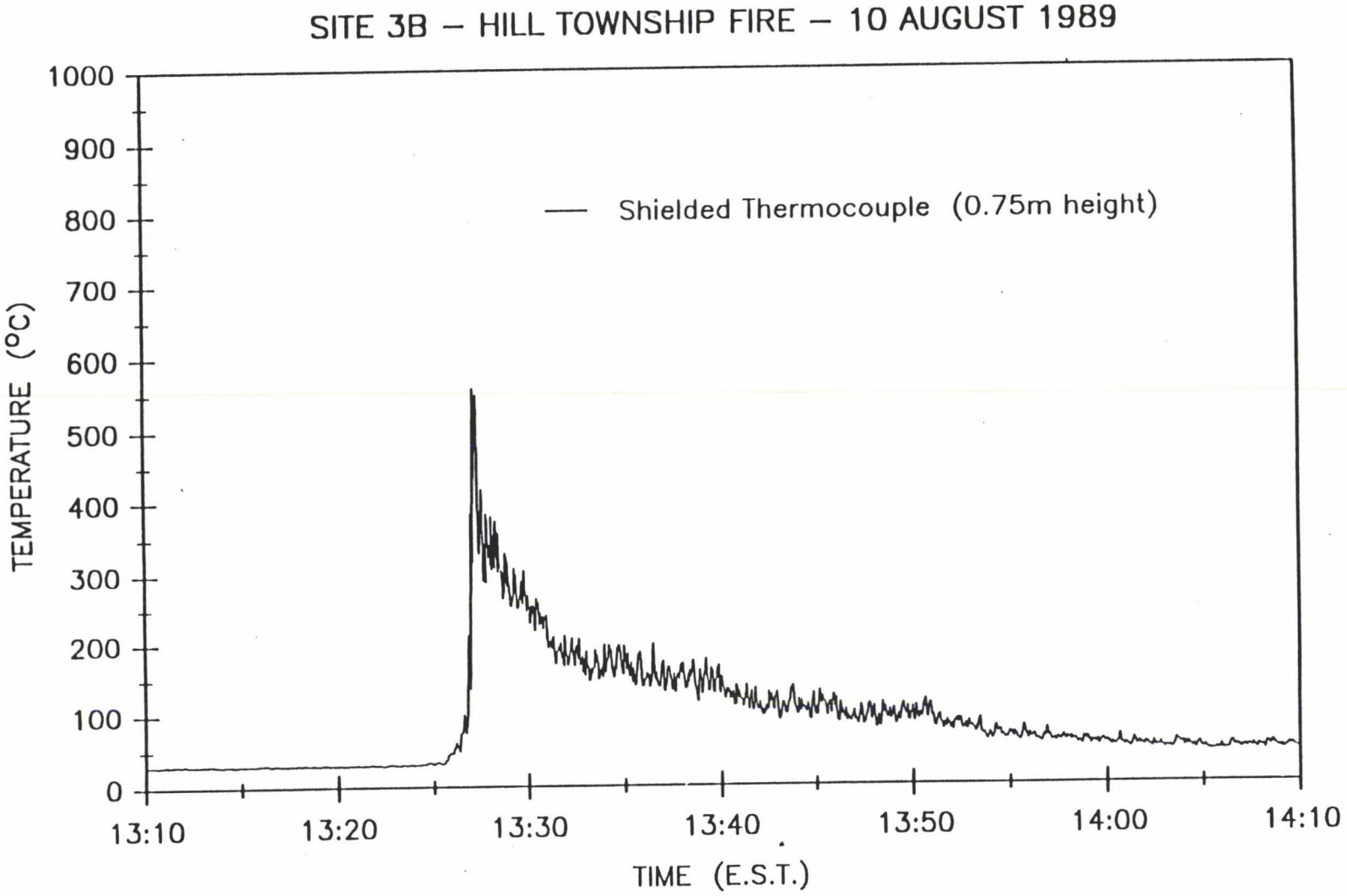

SITE 3A – HILL TOWNSHIP FIRE – 10 AUGUST 1989
Shielded Thermocouple (0.75m height)
TEMPERATURE (°C)
1000
900
800
700
600
500
400
300
200
100
0
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)

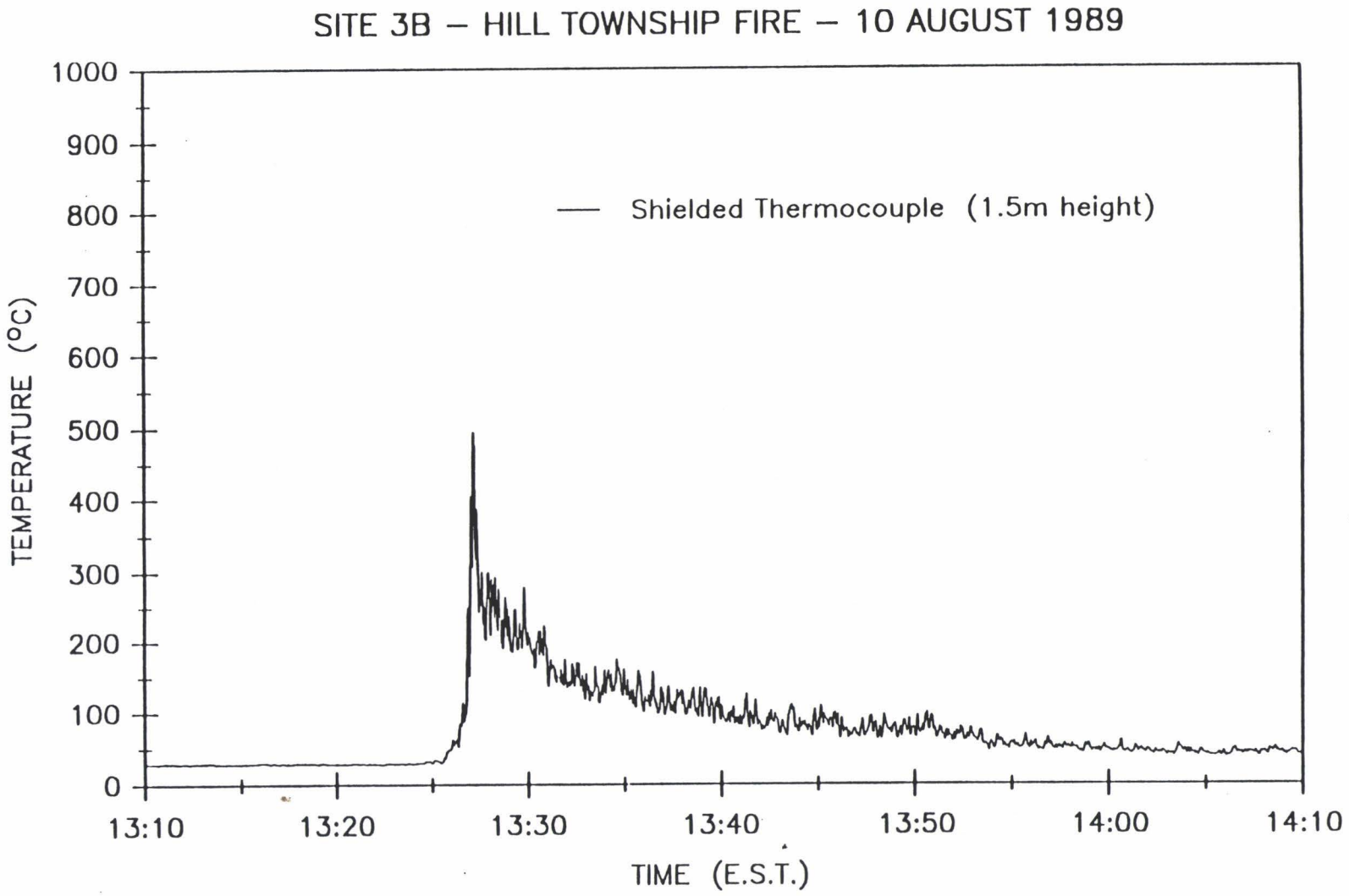

SITE 3A – HILL TOWNSHIP FIRE – 10 AUGUST 1989
Shielded Thermocouple (1.5m height)
TEMPERATURE (°C)
1000
900
800
700
600
500
400
300
200
100
0
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)

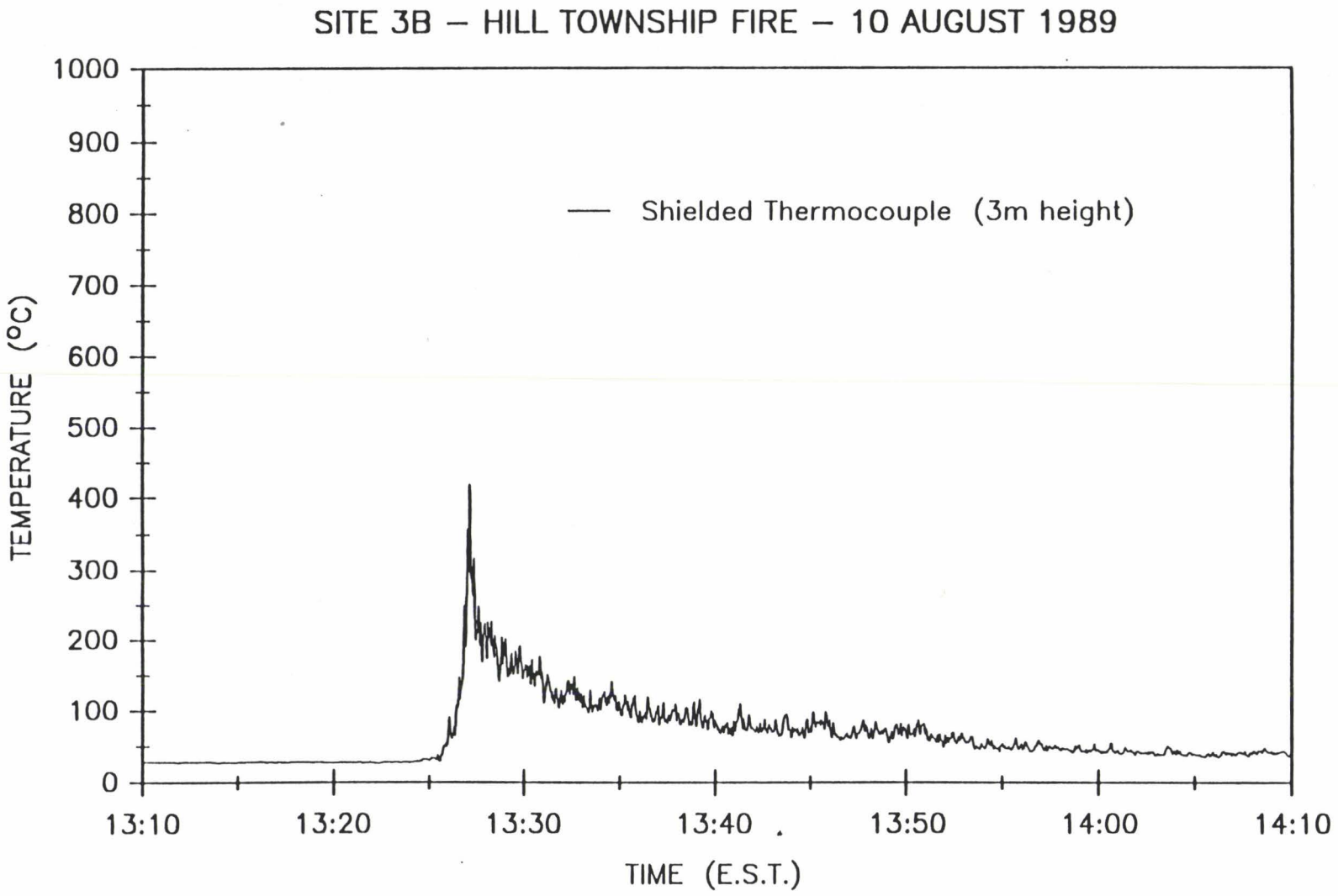

SITE 3A – HILL TOWNSHIP FIRE – 10 AUGUST 1989
Shielded Thermocouple (3m height)
TEMPERATURE (°C)
1000
900
800
700
600
500
400
300
200
100
0
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)

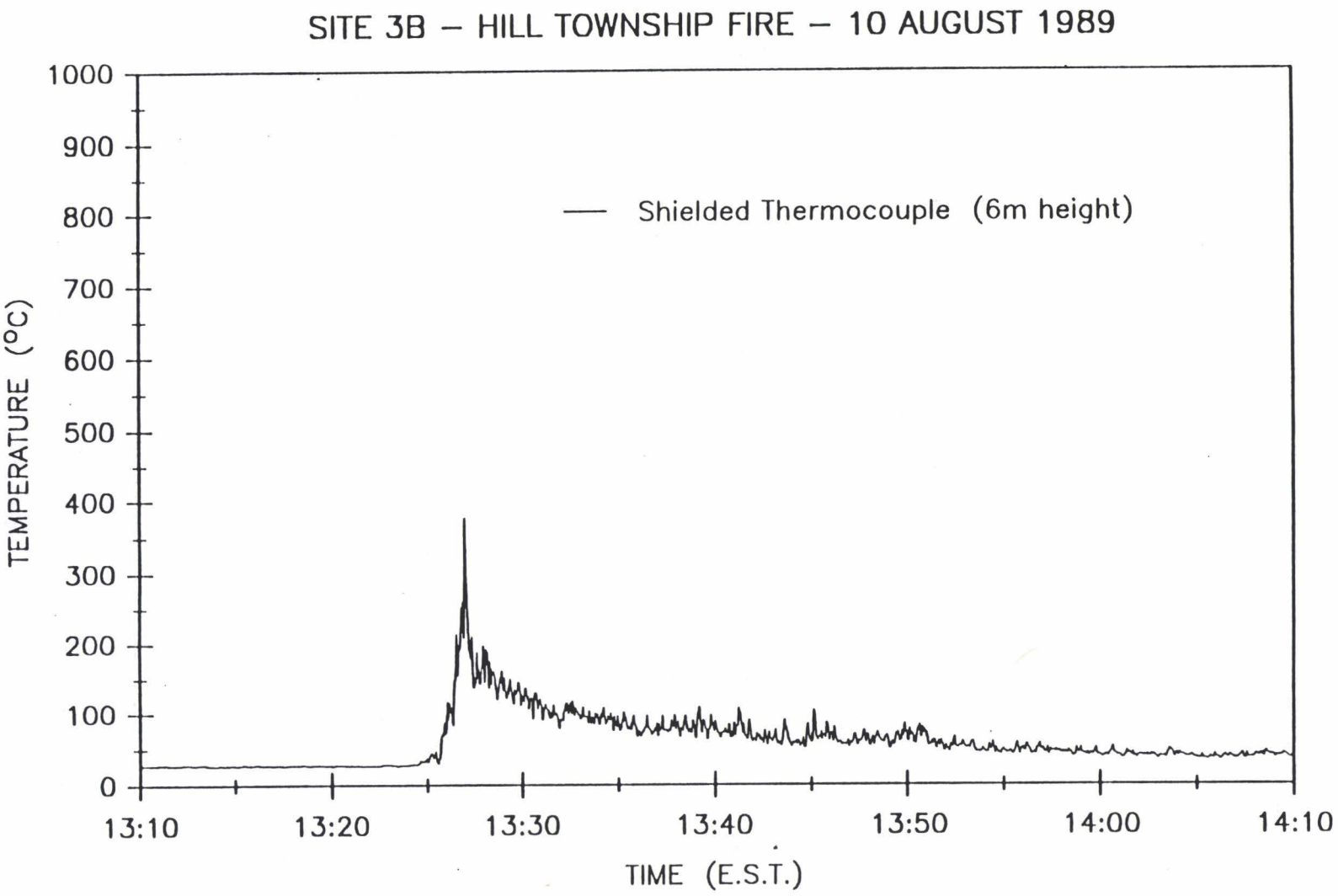

SITE 3A – HILL TOWNSHIP FIRE – 10 AUGUST 1989
Shielded Thermocouple (6m height)
TEMPERATURE (°C)
1000
900
800
700
600
500
400
300
200
100
0
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)

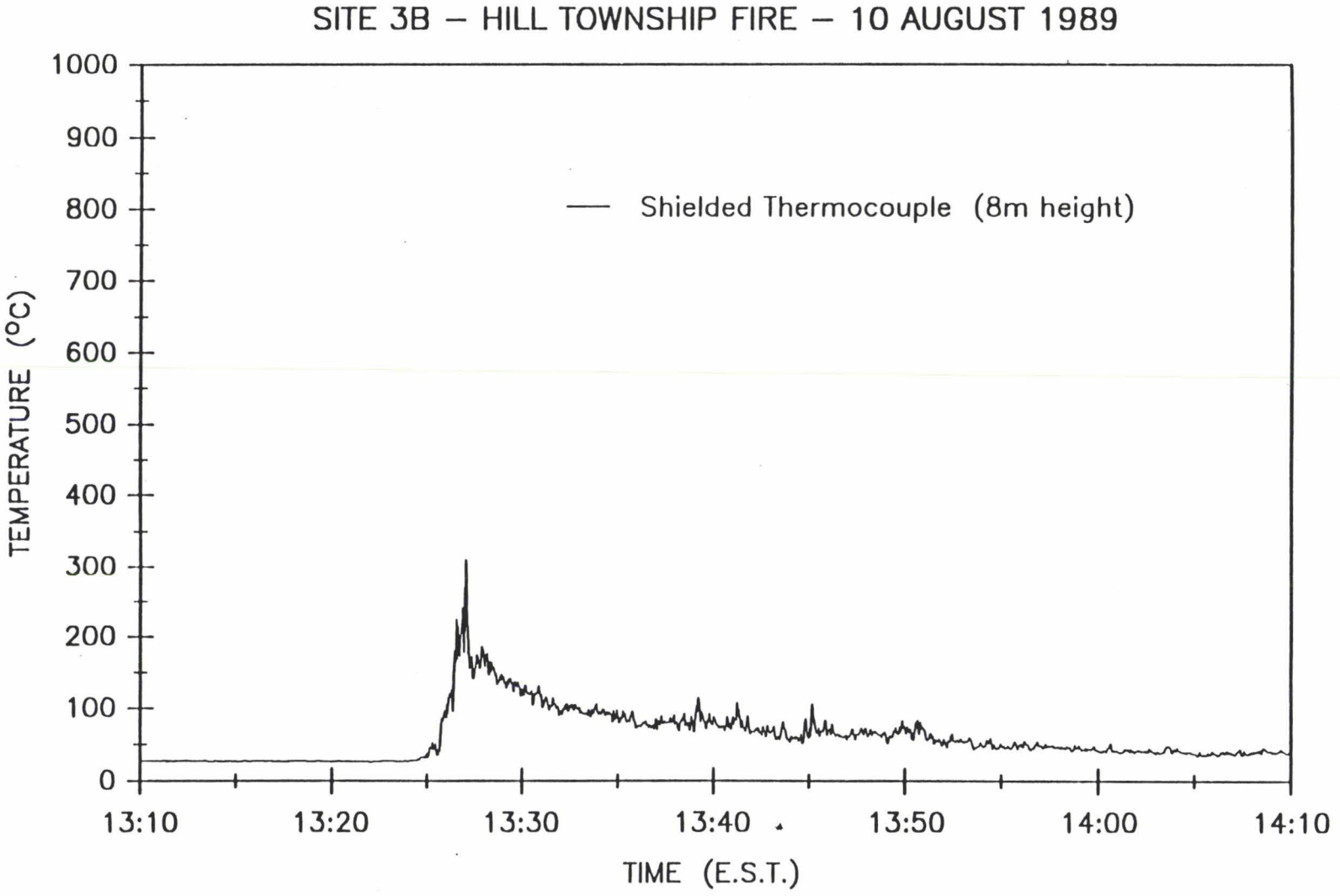

SITE 3A – HILL TOWNSHIP FIRE – 10 AUGUST 1989
Shielded Thermocouple (8m height)
TEMPERATURE (°C)
1000
900
800
700
600
500
400
300
200
100
0
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)

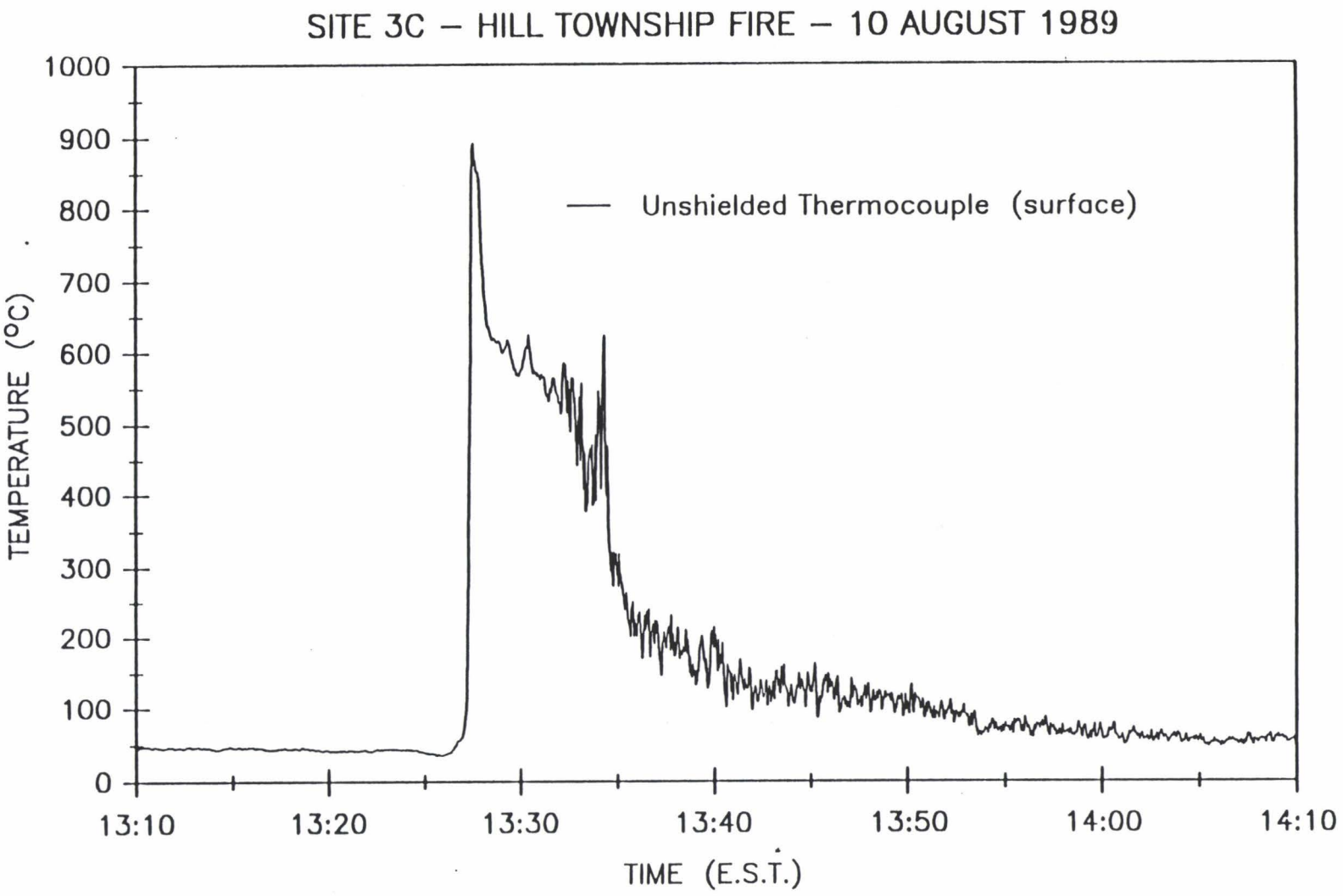

SITE 3B – HILL TOWNSHIP FIRE – 10 AUGUST 1989
Shielded Thermocouple (0.75m height)
TEMPERATURE (°C)
1000
900
800
700
600
500
400
300
200
100
0
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)

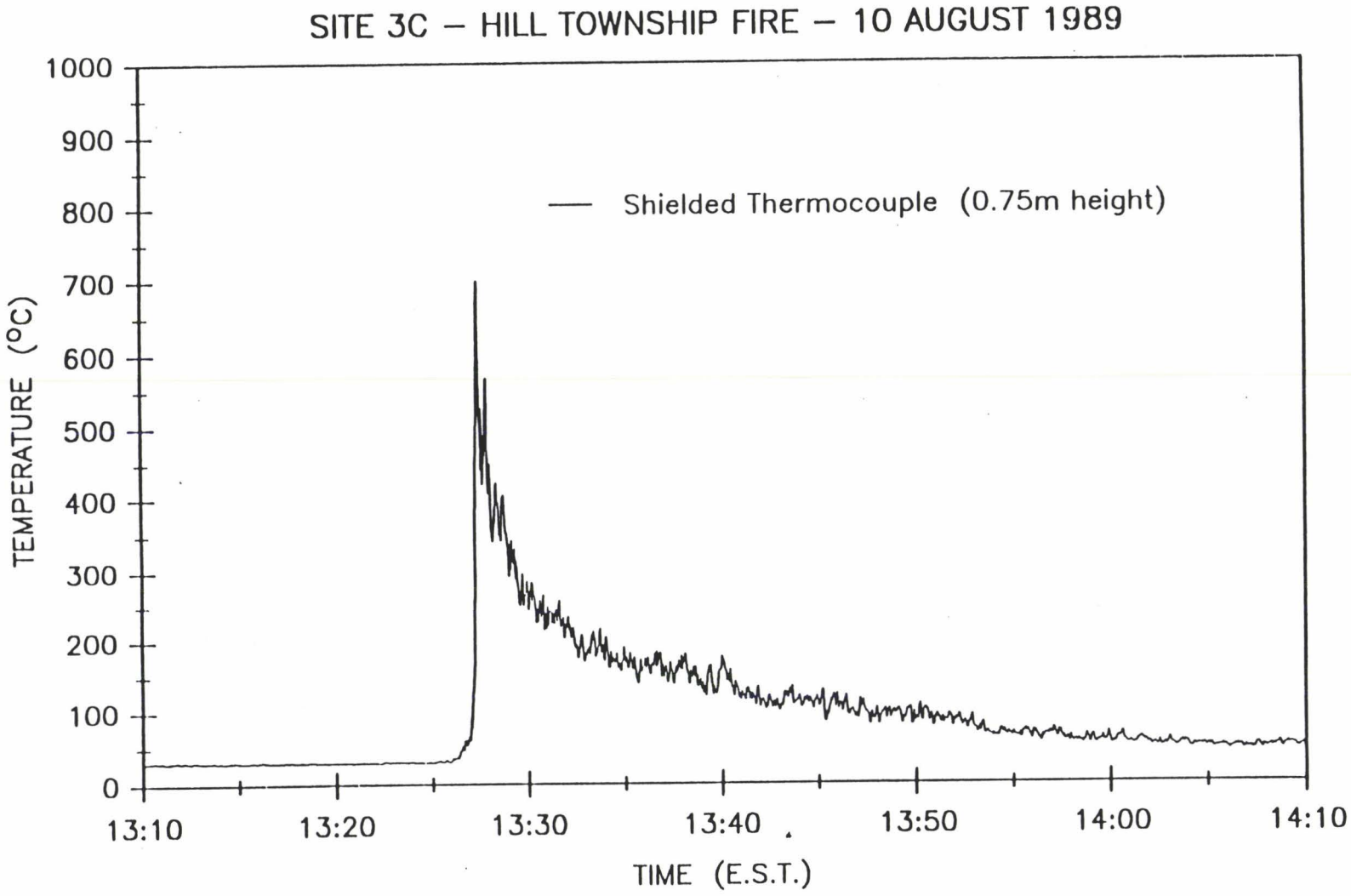

SITE 3B – HILL TOWNSHIP FIRE – 10 AUGUST 1989
Shielded Thermocouple (1.5m height)
TEMPERATURE (°C)
1000
900
800
700
600
500
400
300
200
100
0
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)

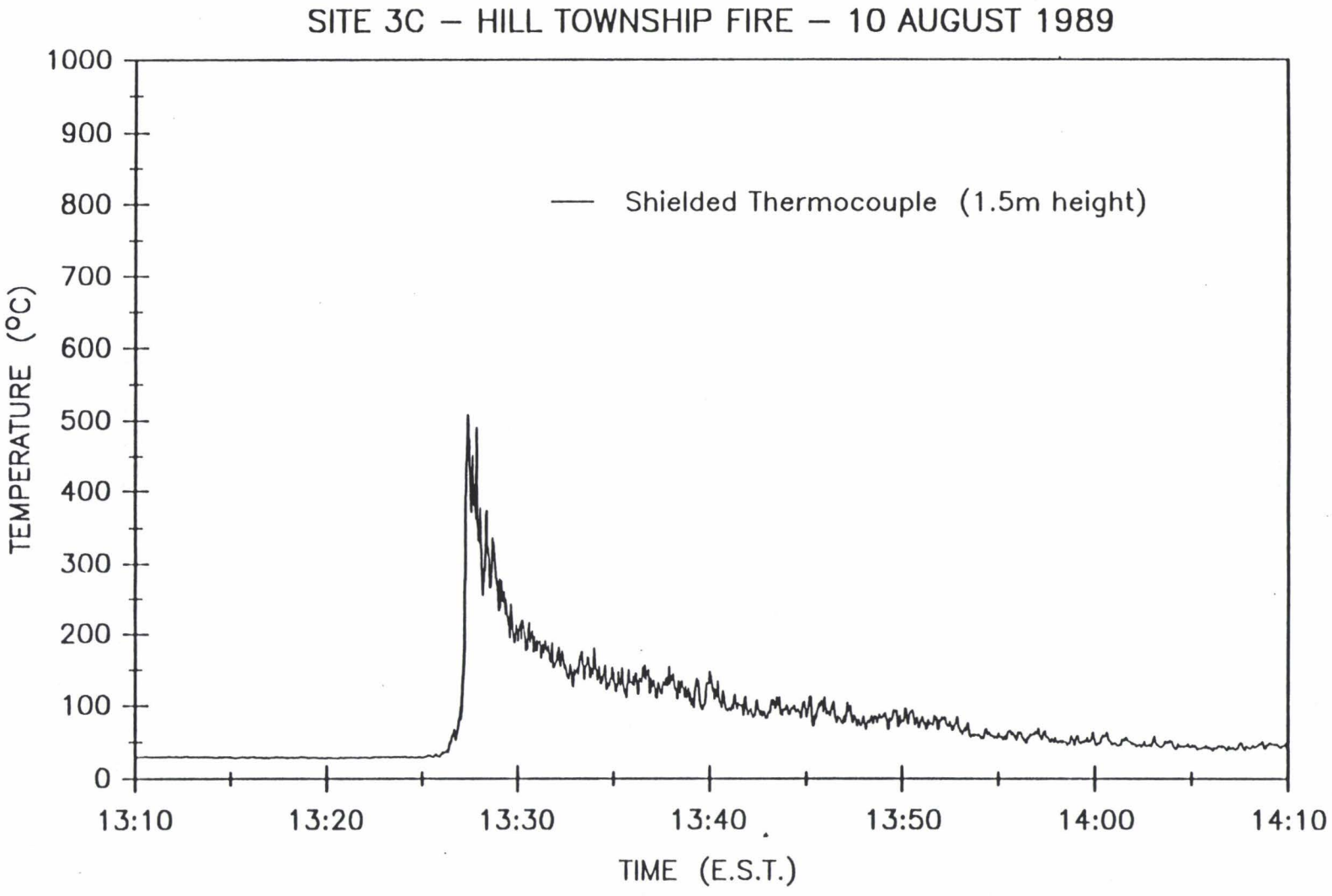

SITE 3B – HILL TOWNSHIP FIRE – 10 AUGUST 1989
Shielded Thermocouple (3m height)
TEMPERATURE (°C)
1000
900
800
700
600
500
400
300
200
100
0
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)

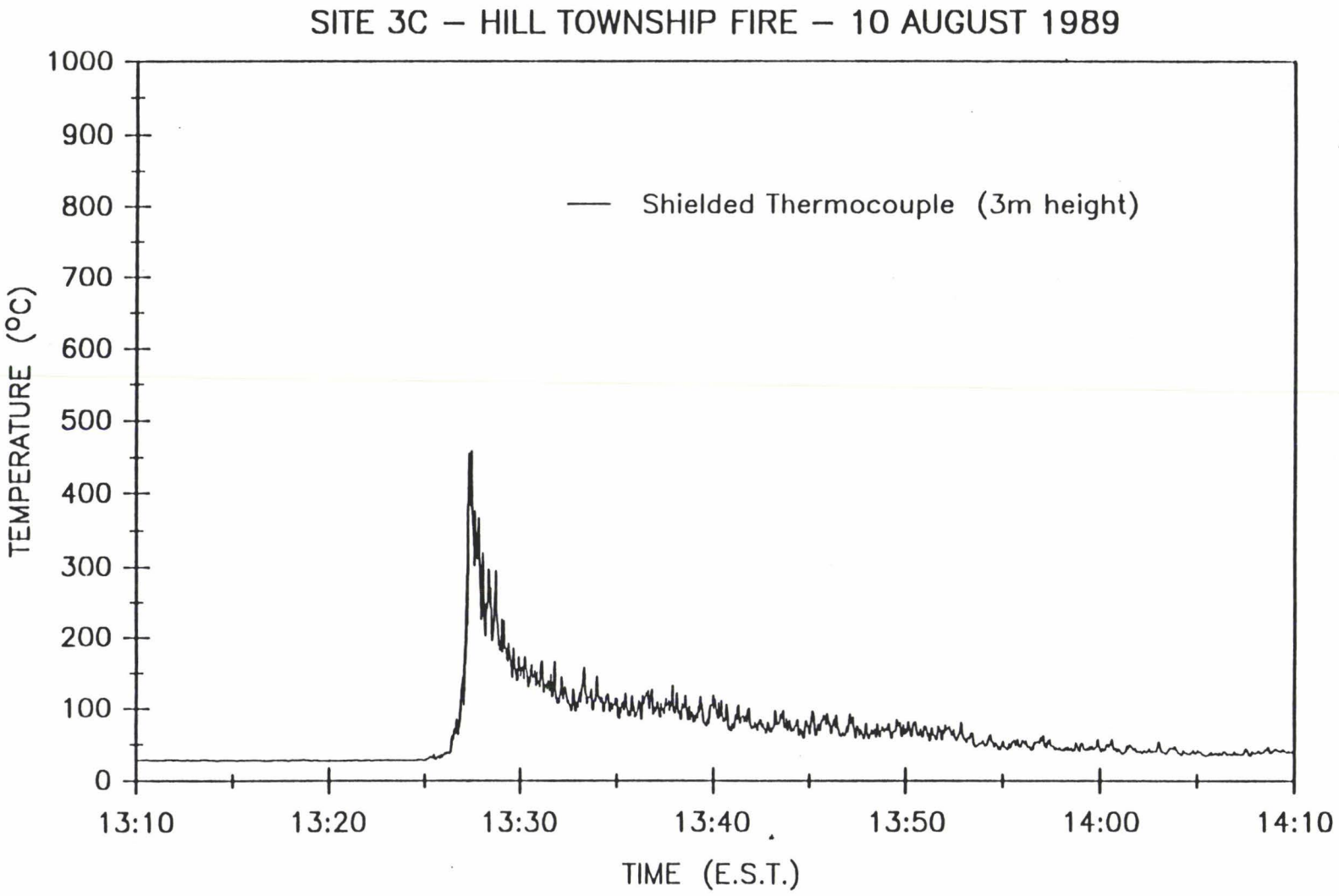

SITE 3B – HILL TOWNSHIP FIRE – 10 AUGUST 1989
Shielded Thermocouple (6m height)
TEMPERATURE (°C)
1000
900
800
700
600
500
400
300
200
100
0
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)

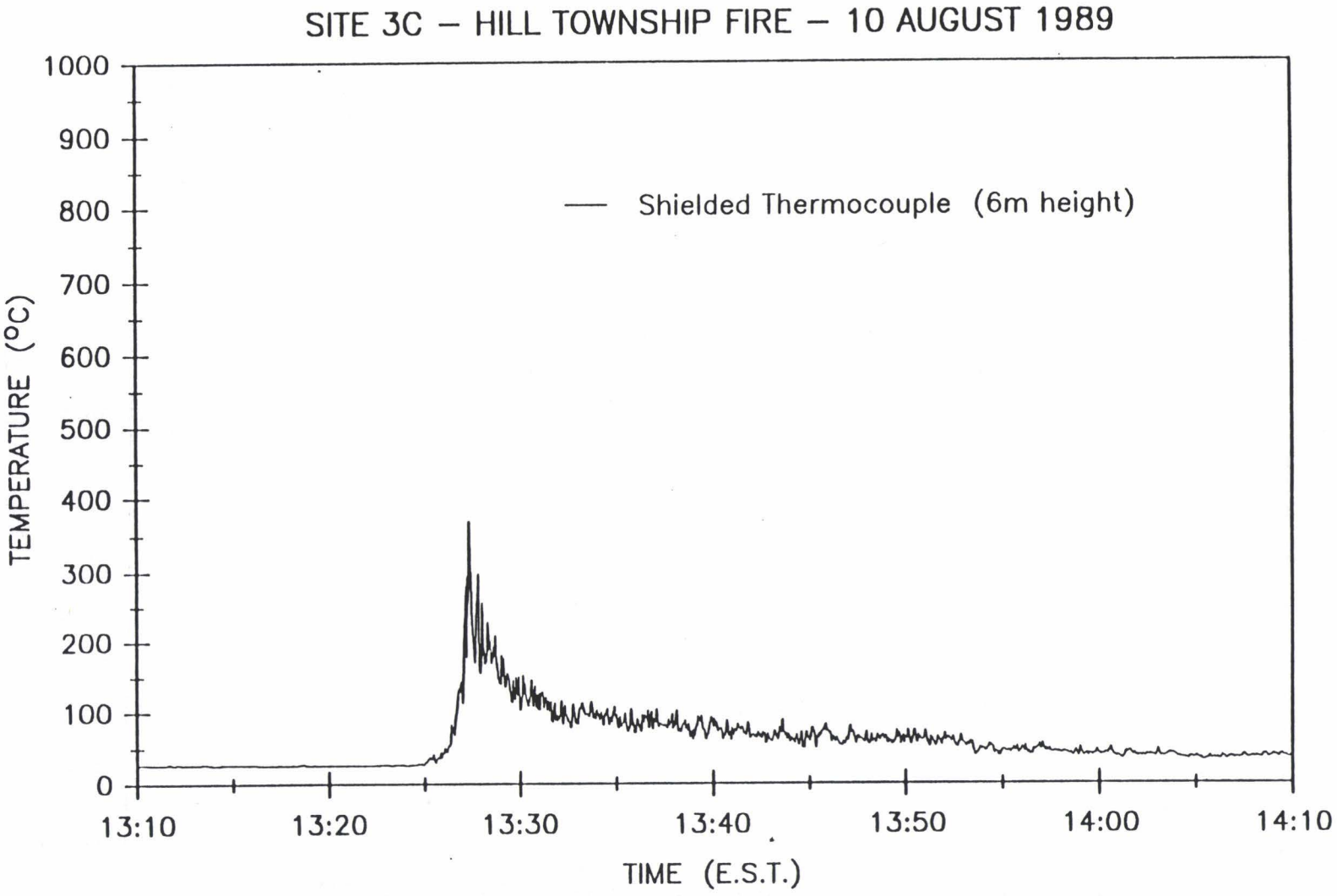

SITE 3B – HILL TOWNSHIP FIRE – 10 AUGUST 1989
Shielded Thermocouple (8m height)
TEMPERATURE (°C)
1000
900
800
700
600
500
400
300
200
100
0
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)

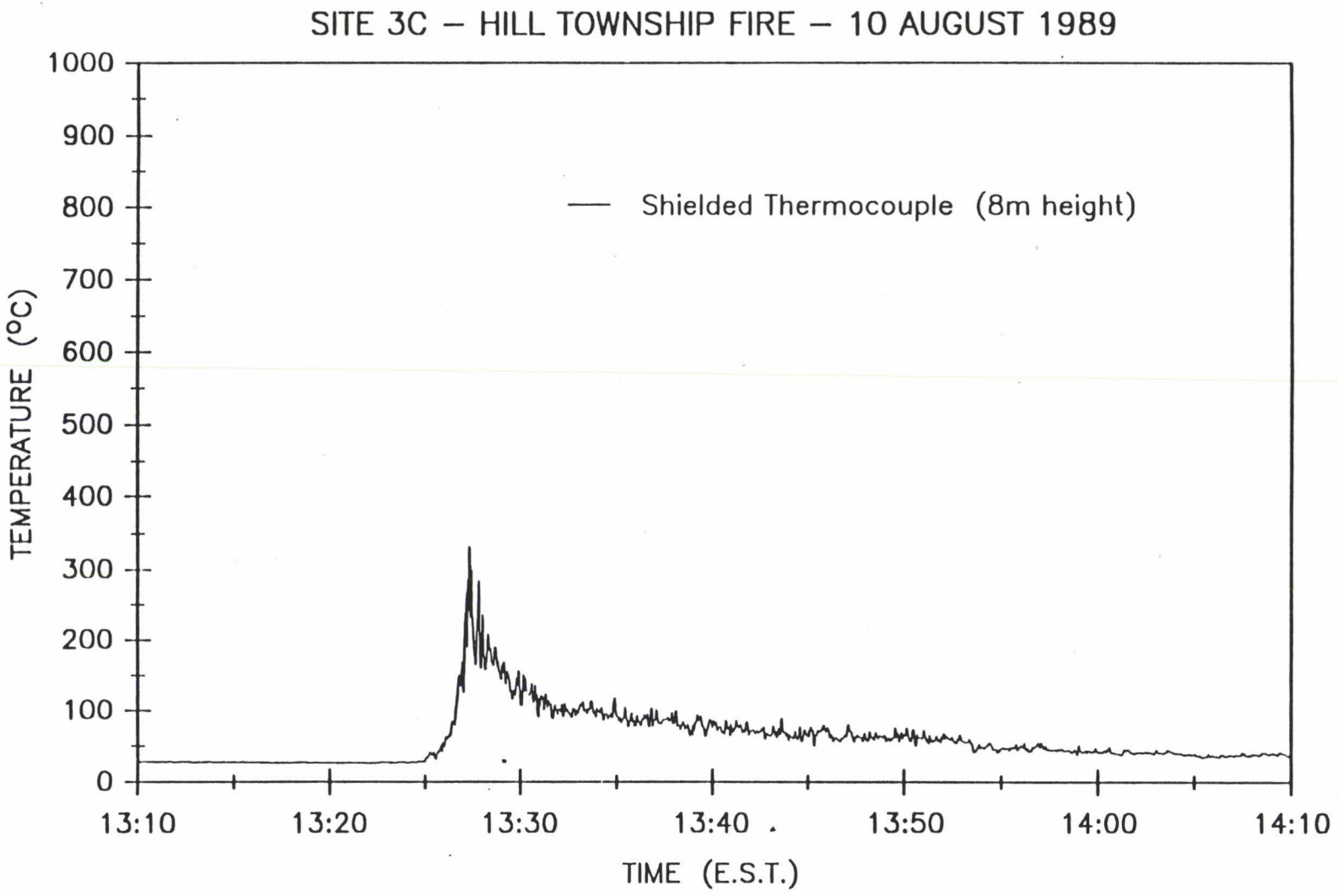

SITE 3C – HILL TOWNSHIP FIRE – 10 AUGUST 1989
Unshielded Thermocouple (surface)
TEMPERATURE (°C)
1000
900
800
700
600
500
400
300
200
100
0
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)

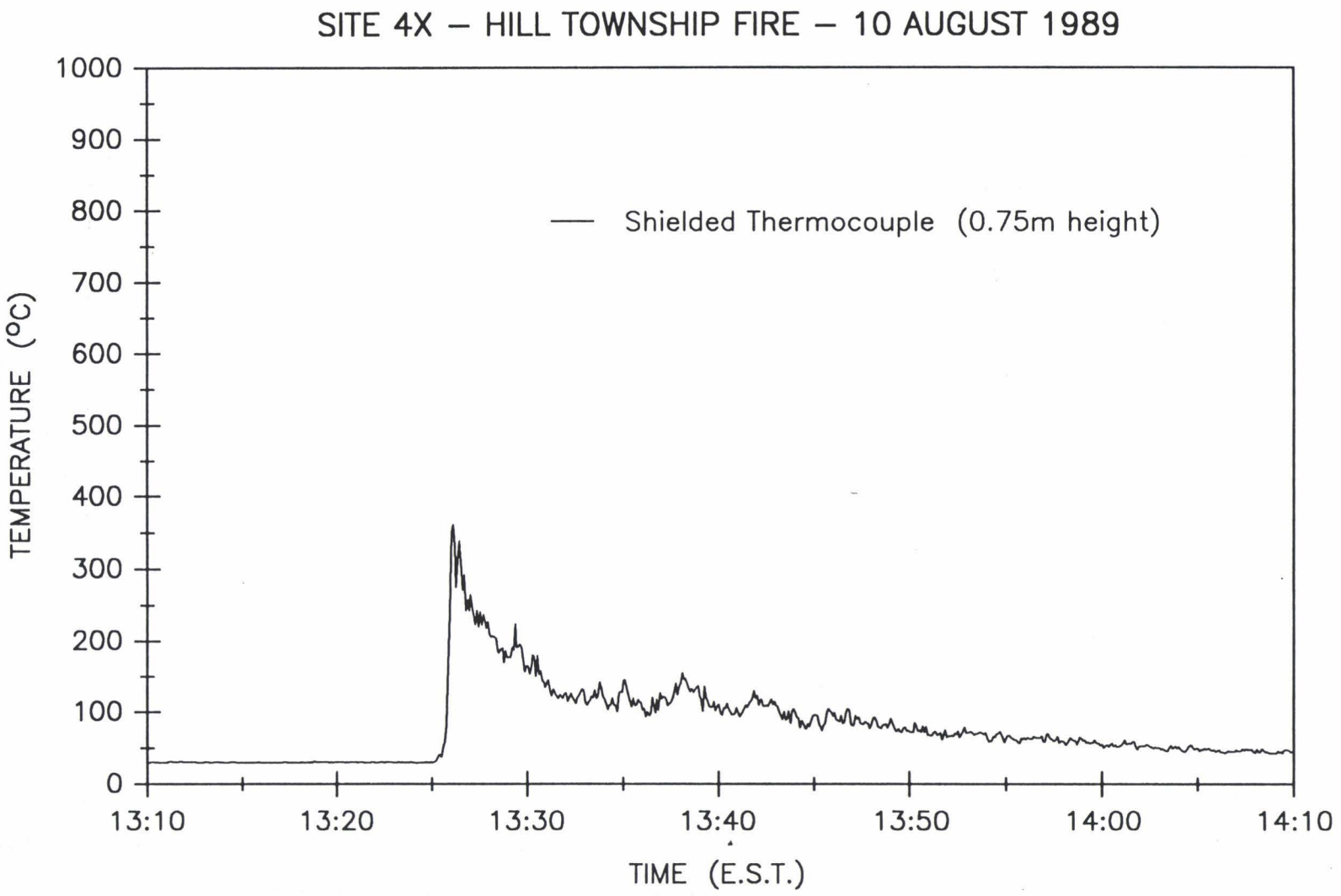

SITE 3C – HILL TOWNSHIP FIRE – 10 AUGUST 1989
Shielded Thermocouple (0.75m height)
TEMPERATURE (°C)
1000
900
800
700
600
500
400
300
200
100
0
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)

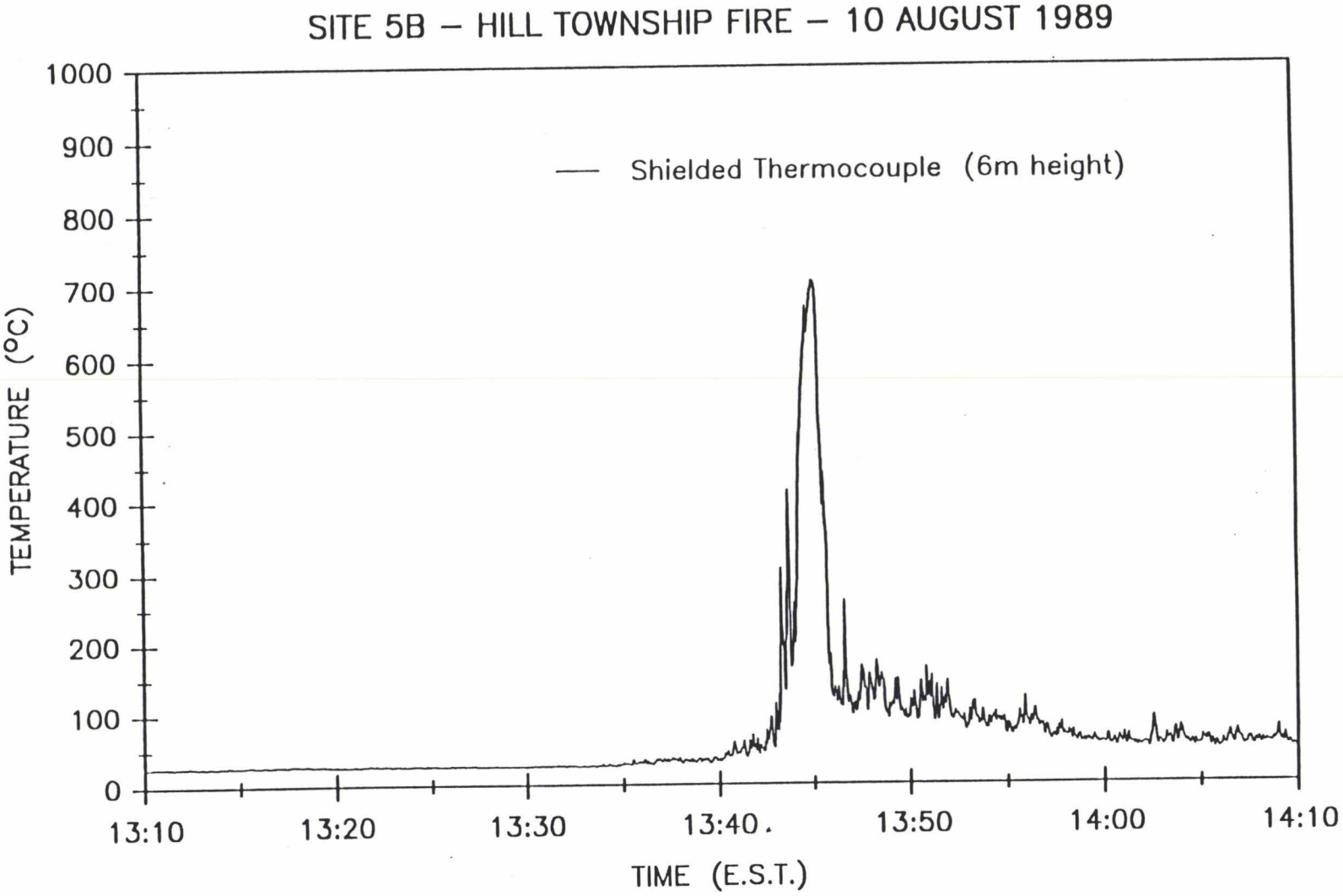

SITE 3C – HILL TOWNSHIP FIRE – 10 AUGUST 1989
Shielded Thermocouple (1.5m height)
TEMPERATURE (°C)
1000
900
800
700
600
500
400
300
200
100
0
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)

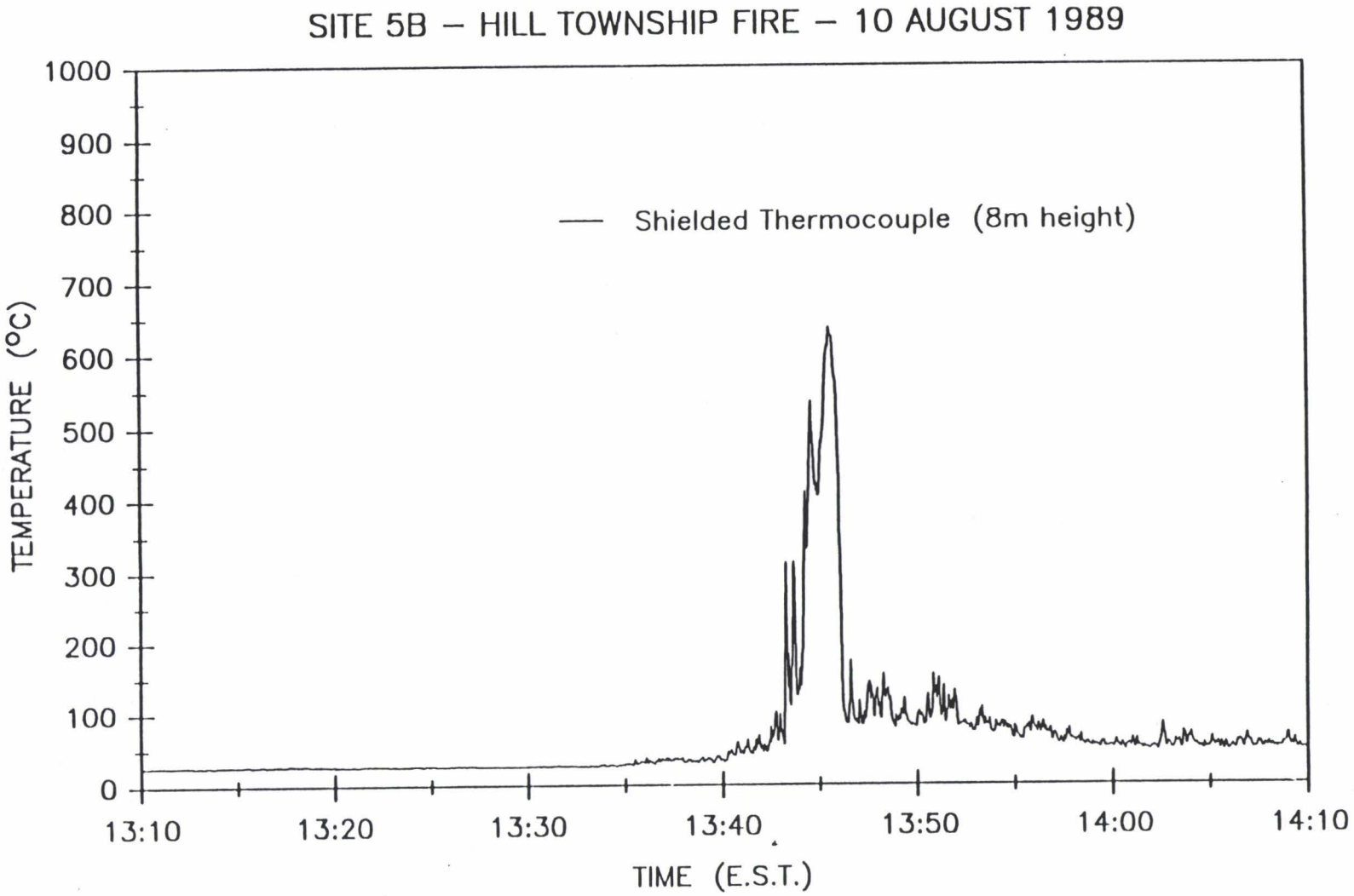

SITE 3C – HILL TOWNSHIP FIRE – 10 AUGUST 1989
Shielded Thermocouple (3m height)
TEMPERATURE (°C)
1000
900
800
700
600
500
400
300
200
100
0
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)

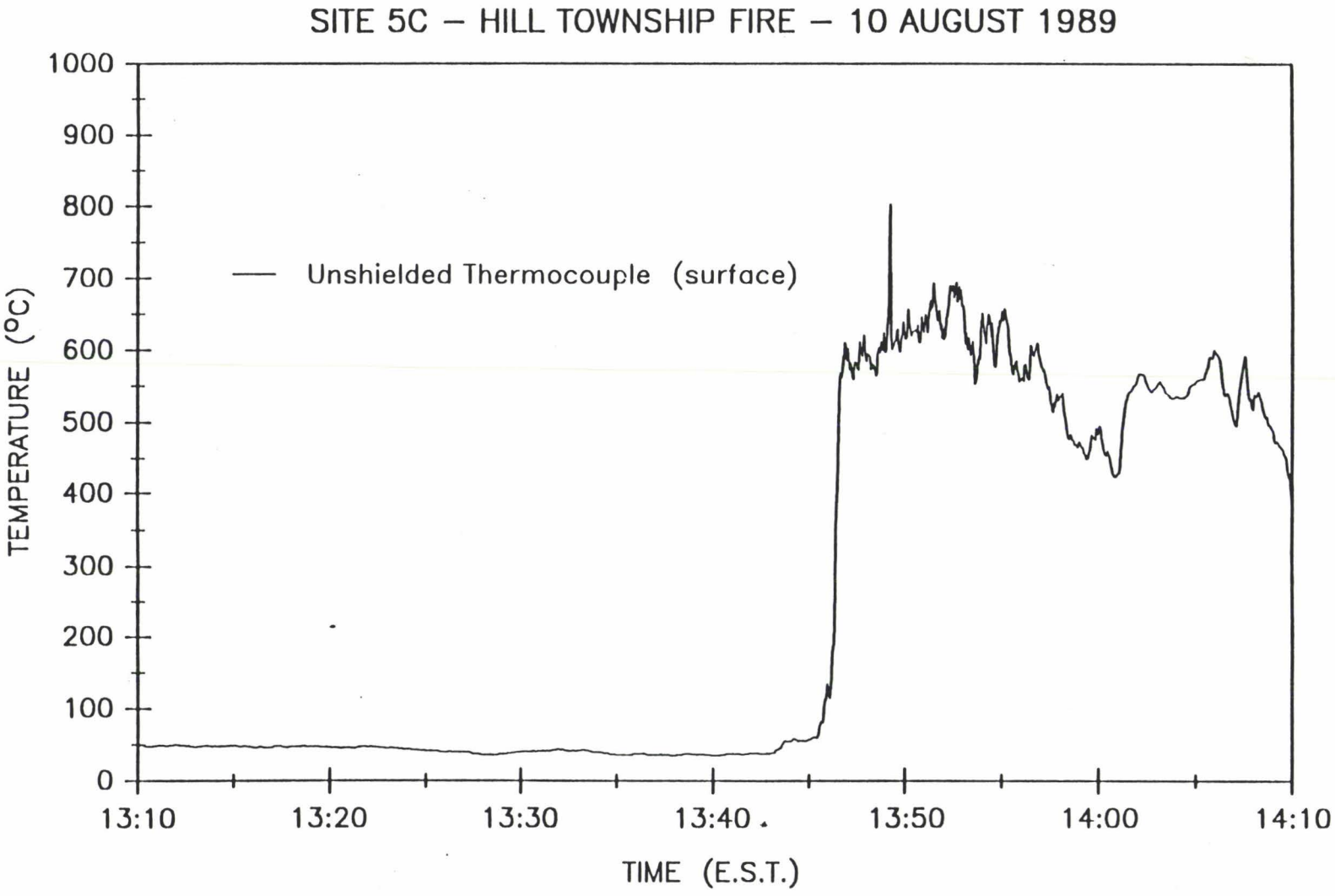

SITE 3C – HILL TOWNSHIP FIRE – 10 AUGUST 1989
Shielded Thermocouple (6m height)
TEMPERATURE (°C)
1000
900
800
700
600
500
400
300
200
100
0
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)

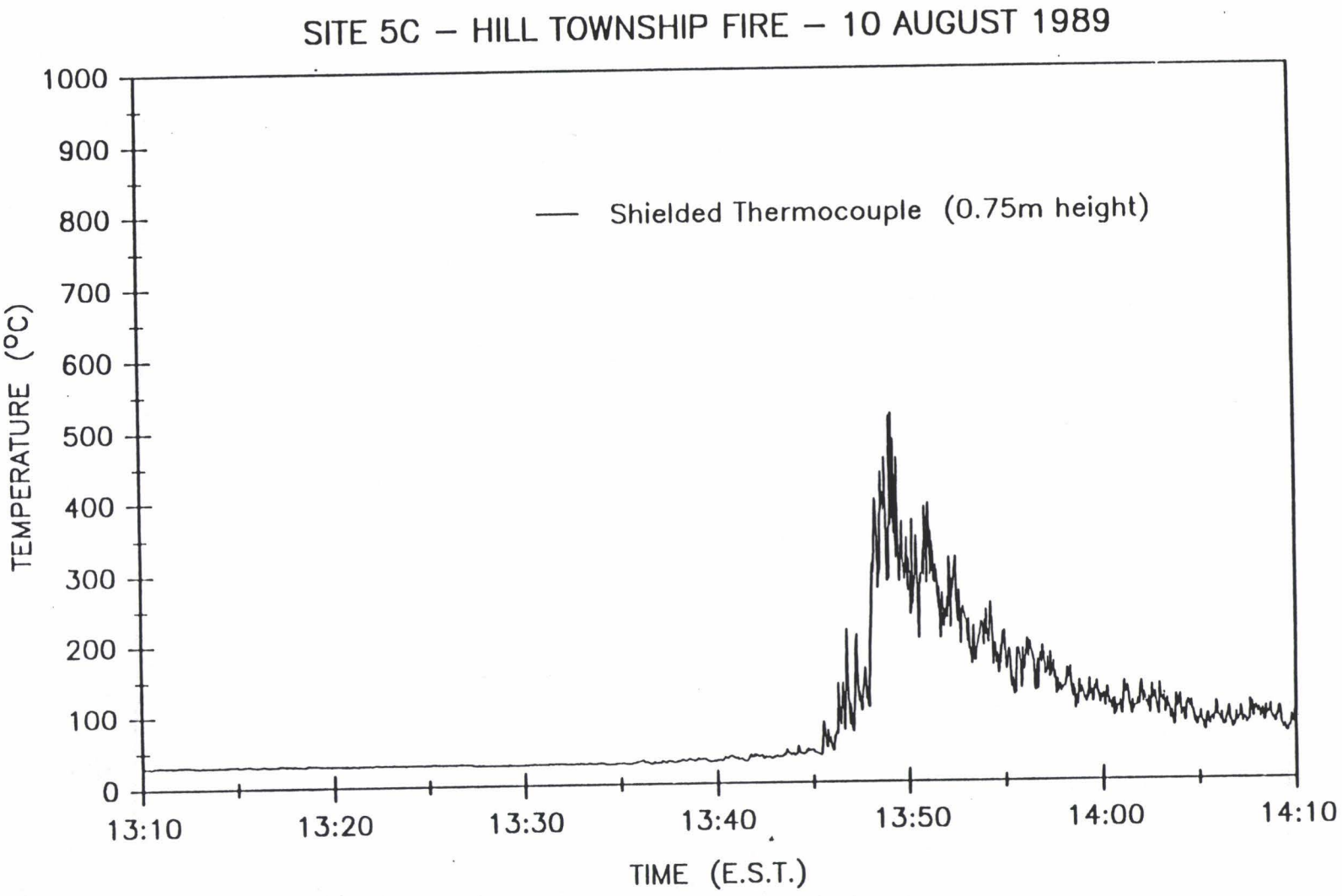

SITE 3C – HILL TOWNSHIP FIRE – 10 AUGUST 1989
Shielded Thermocouple (8m height)
TEMPERATURE (°C)
1000
900
800
700
600
500
400
300
200
100
0
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)

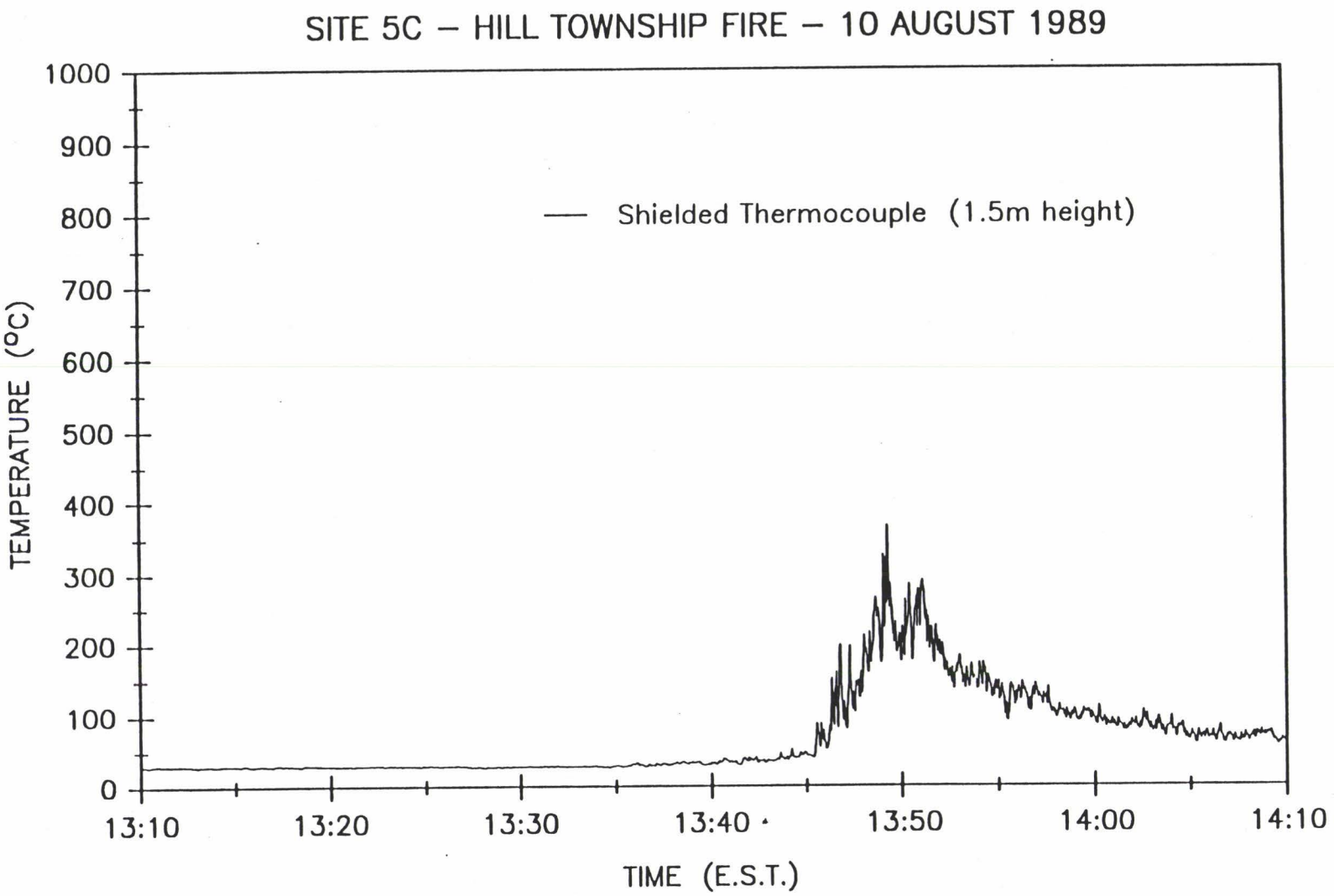

SITE 4X – HILL TOWNSHIP FIRE – 10 AUGUST 1989
1000
900
800
700
600
500
400
300
200
100
0
TEMPERATURE (°C)
Shielded Thermocouple (0.75m height)
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)

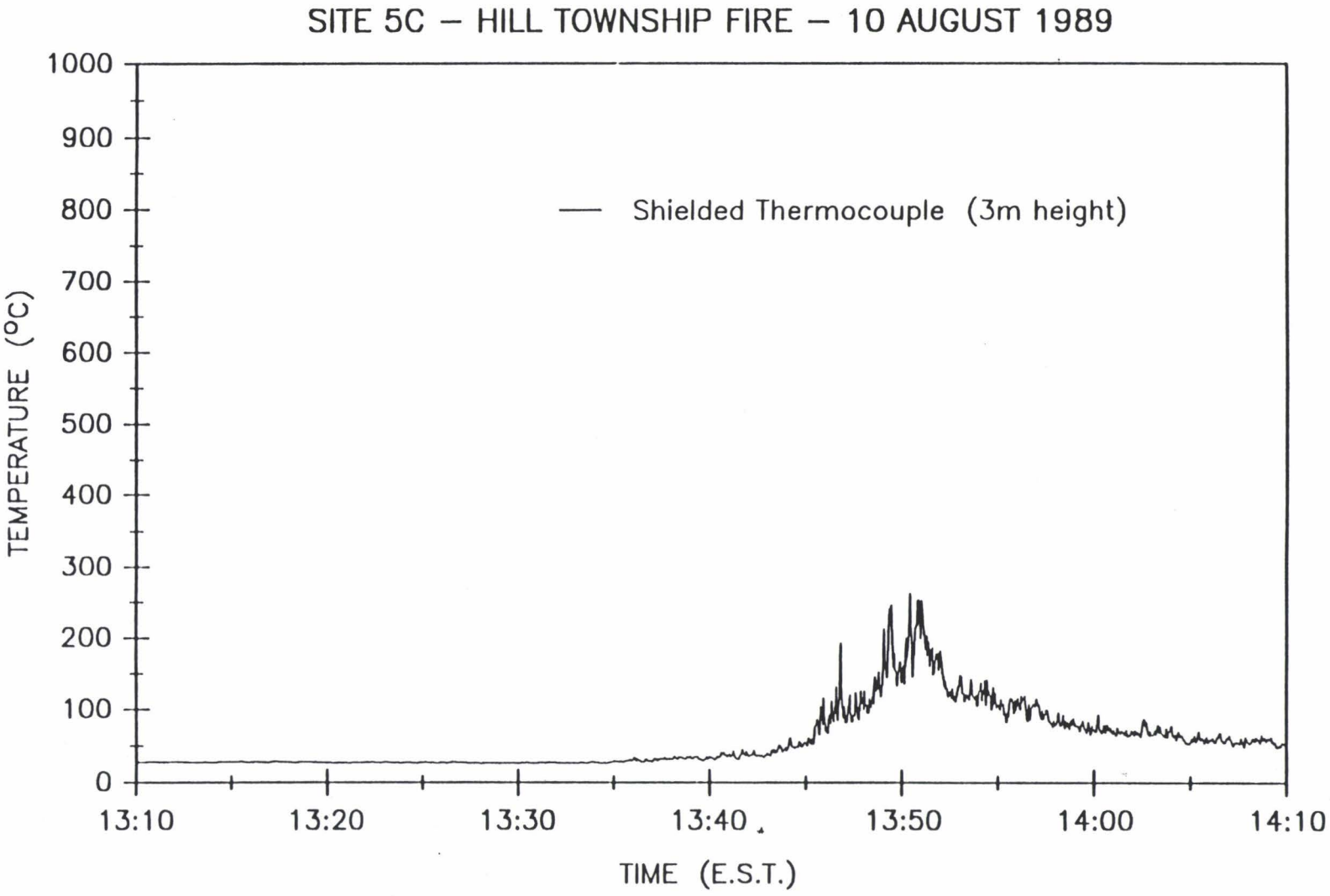

SITE 5B – HILL TOWNSHIP FIRE – 10 AUGUST 1989
Shielded Thermocouple (6m height)
TEMPERATURE (°C)
1000
900
800
700
600
500
400
300
200
100
0
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)

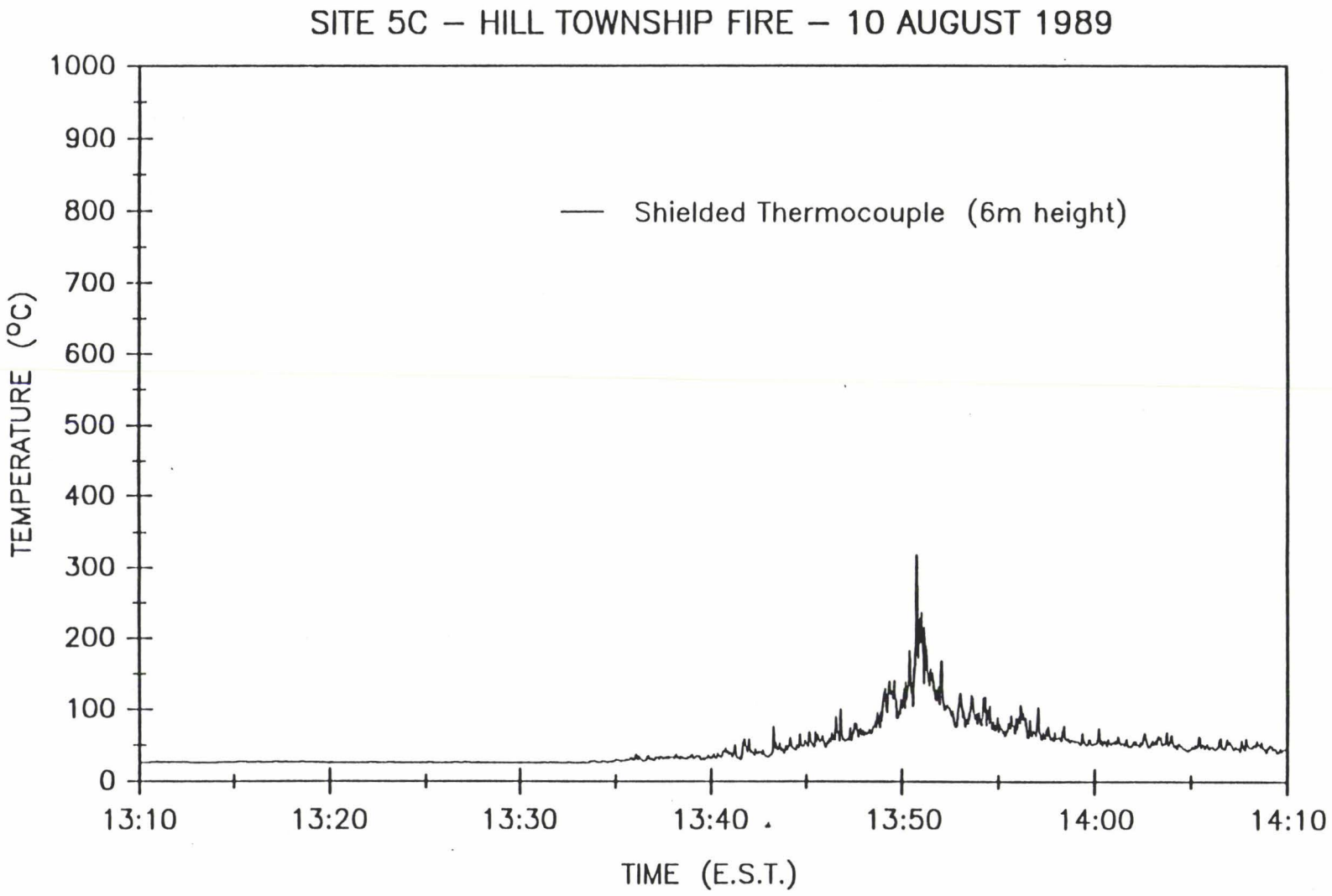

SITE 5B – HILL TOWNSHIP FIRE – 10 AUGUST 1989
Shielded Thermocouple (8m height)
TEMPERATURE (°C)
1000
900
800
700
600
500
400
300
200
100
0
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)

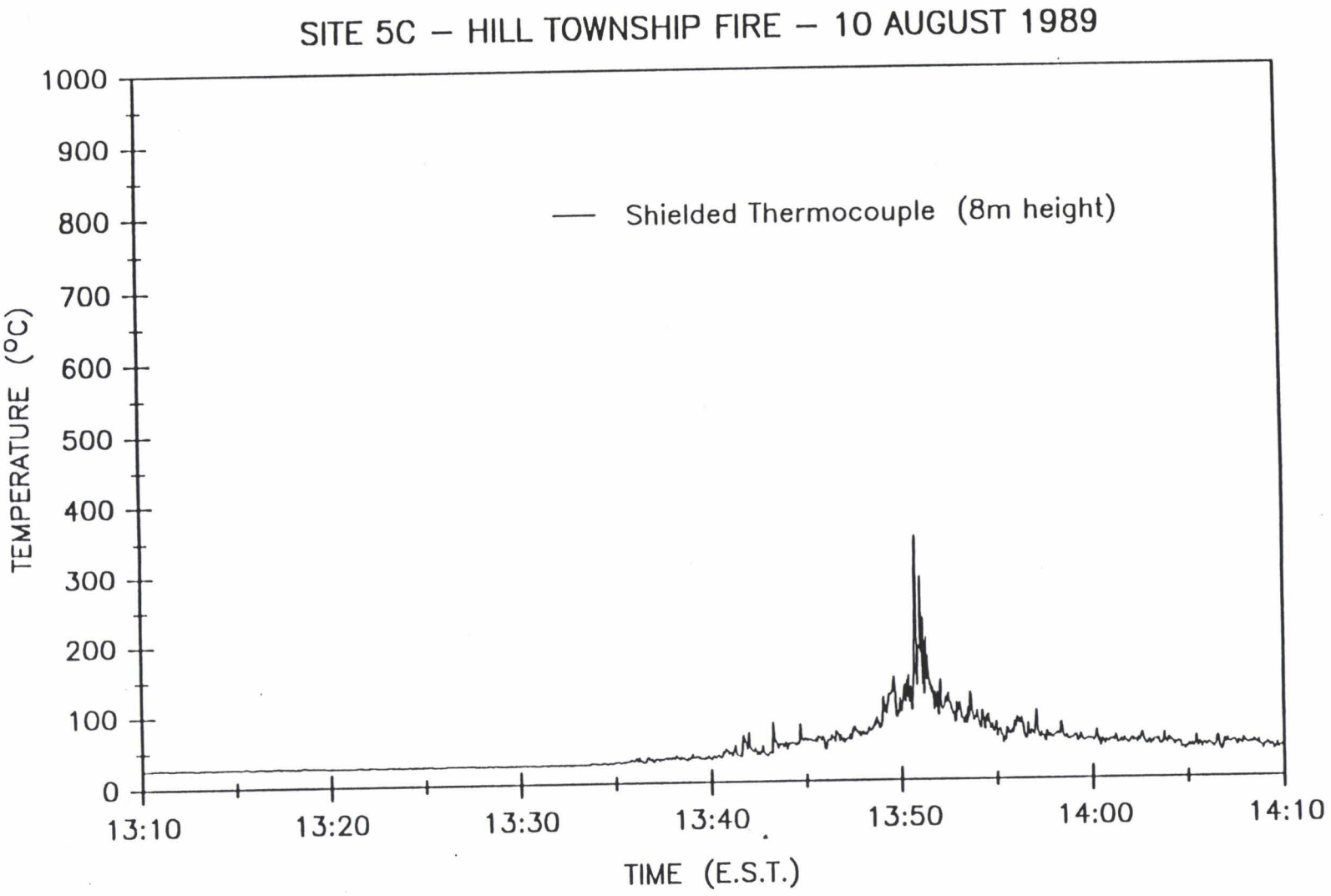

SITE 5C – HILL TOWNSHIP FIRE – 10 AUGUST 1989
1000
900
800
700
600
500
400
300
200
100
0
TEMPERATURE (°C)
Unshielded Thermocouple (surface)
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)

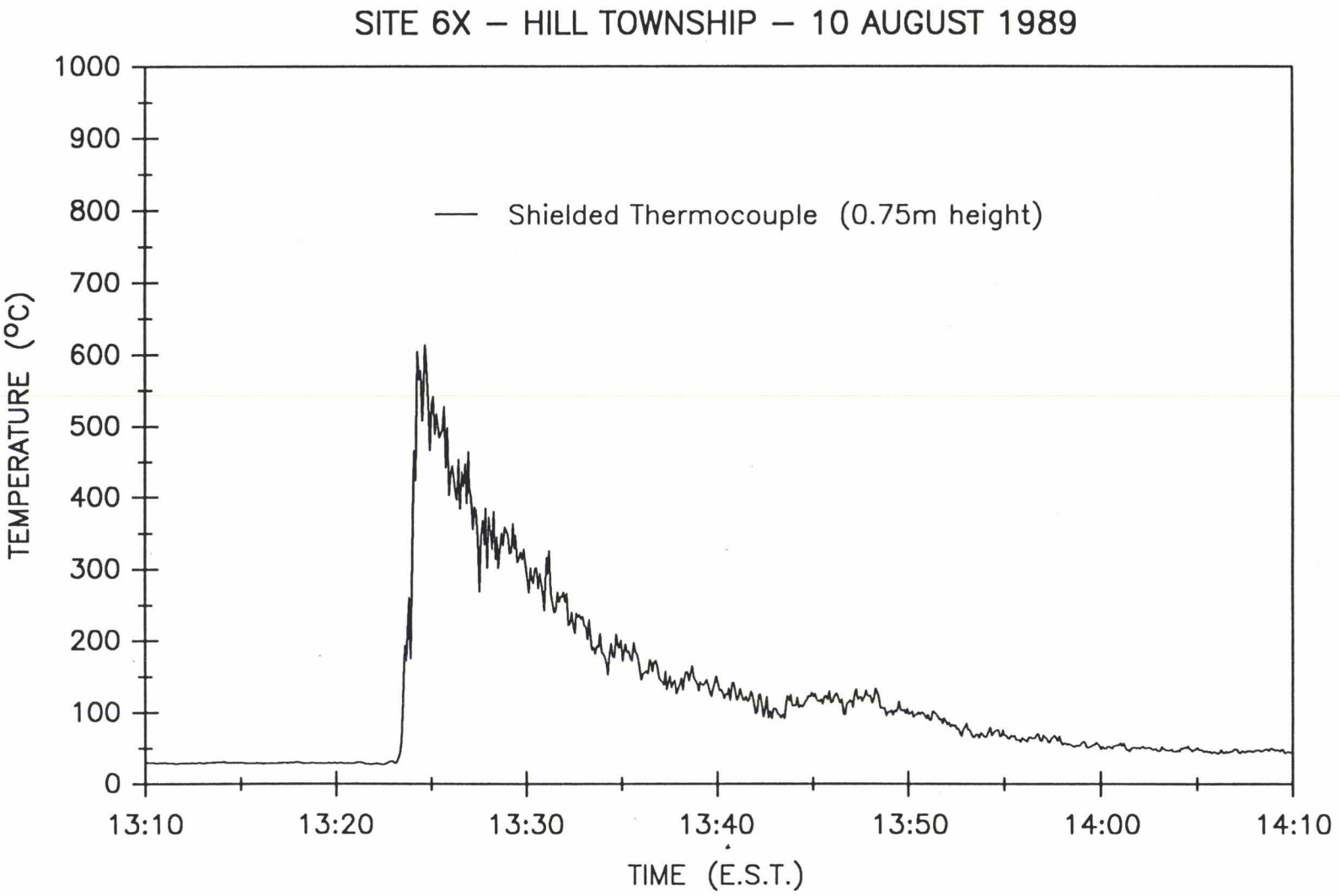

SITE 5C – HILL TOWNSHIP FIRE – 10 AUGUST 1989
Shielded Thermocouple (0.75m height)
TEMPERATURE (°C)
1000
900
800
700
600
500
400
300
200
100
0
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)

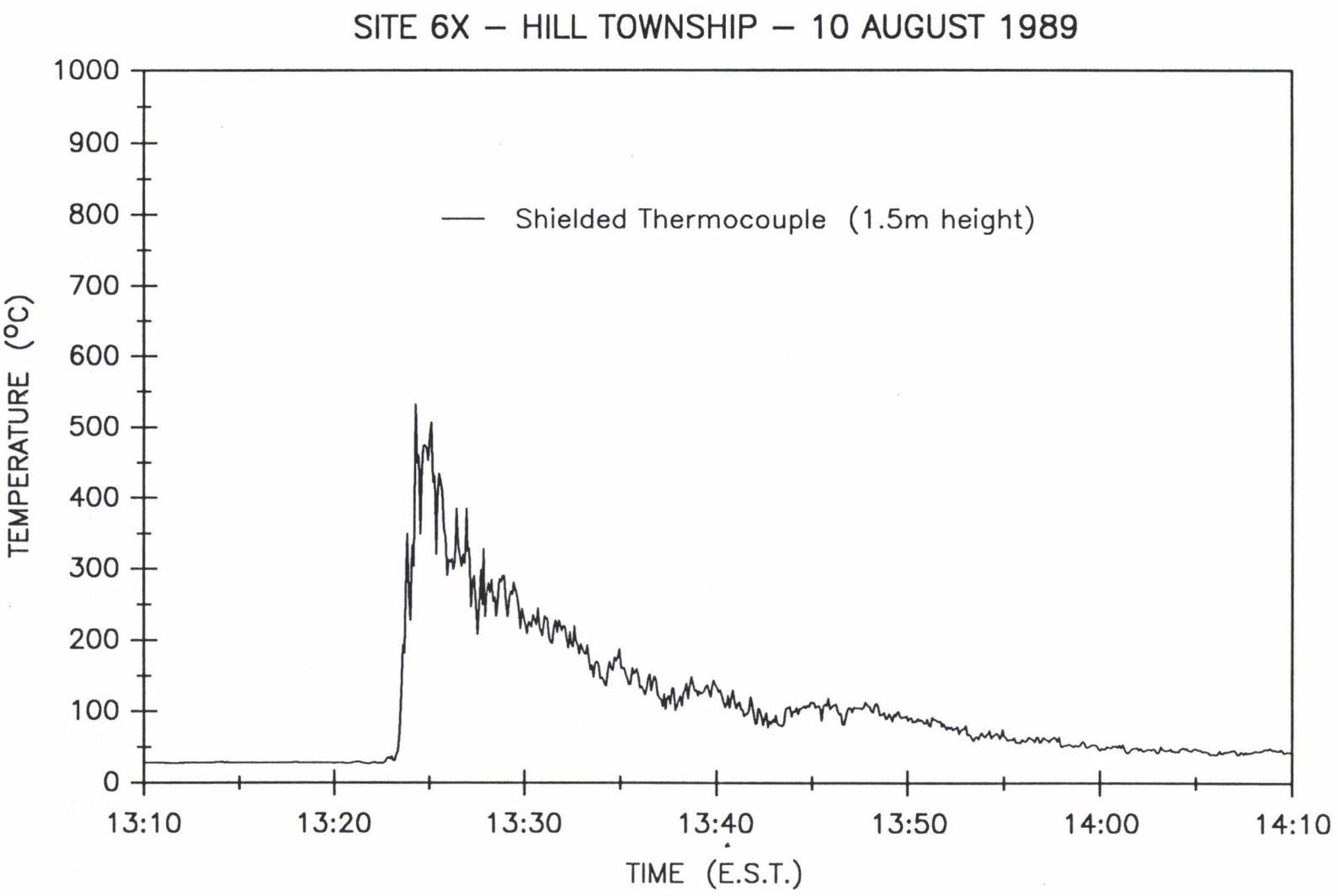

SITE 5C – HILL TOWNSHIP FIRE – 10 AUGUST 1989
Shielded Thermocouple (1.5m height)
TEMPERATURE (°C)
1000
900
800
700
600
500
400
300
200
100
0
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)

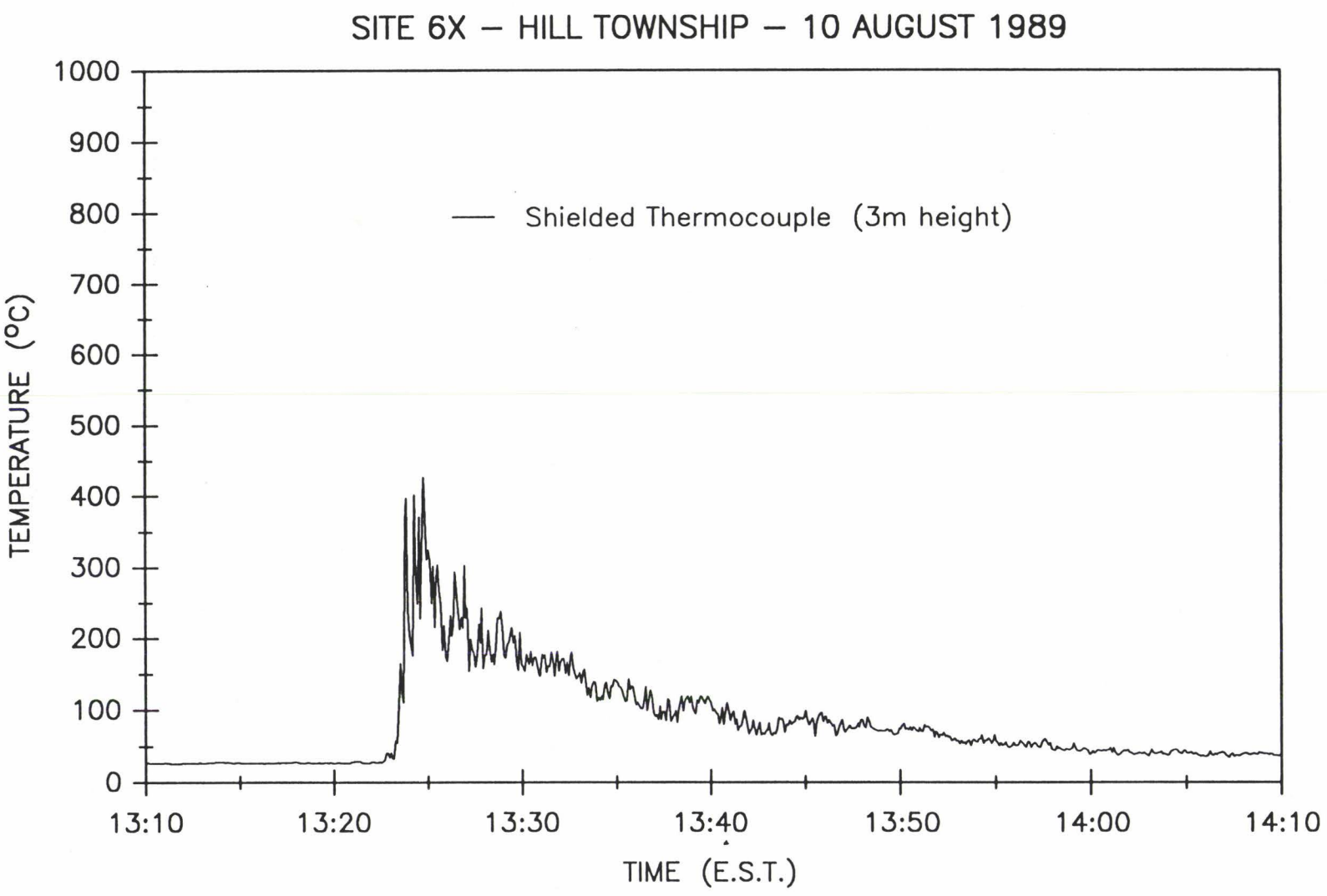

SITE 5C – HILL TOWNSHIP FIRE – 10 AUGUST 1989
Shielded Thermocouple (3m height)
TEMPERATURE (°C)
1000
900
800
700
600
500
400
300
200
100
0
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)

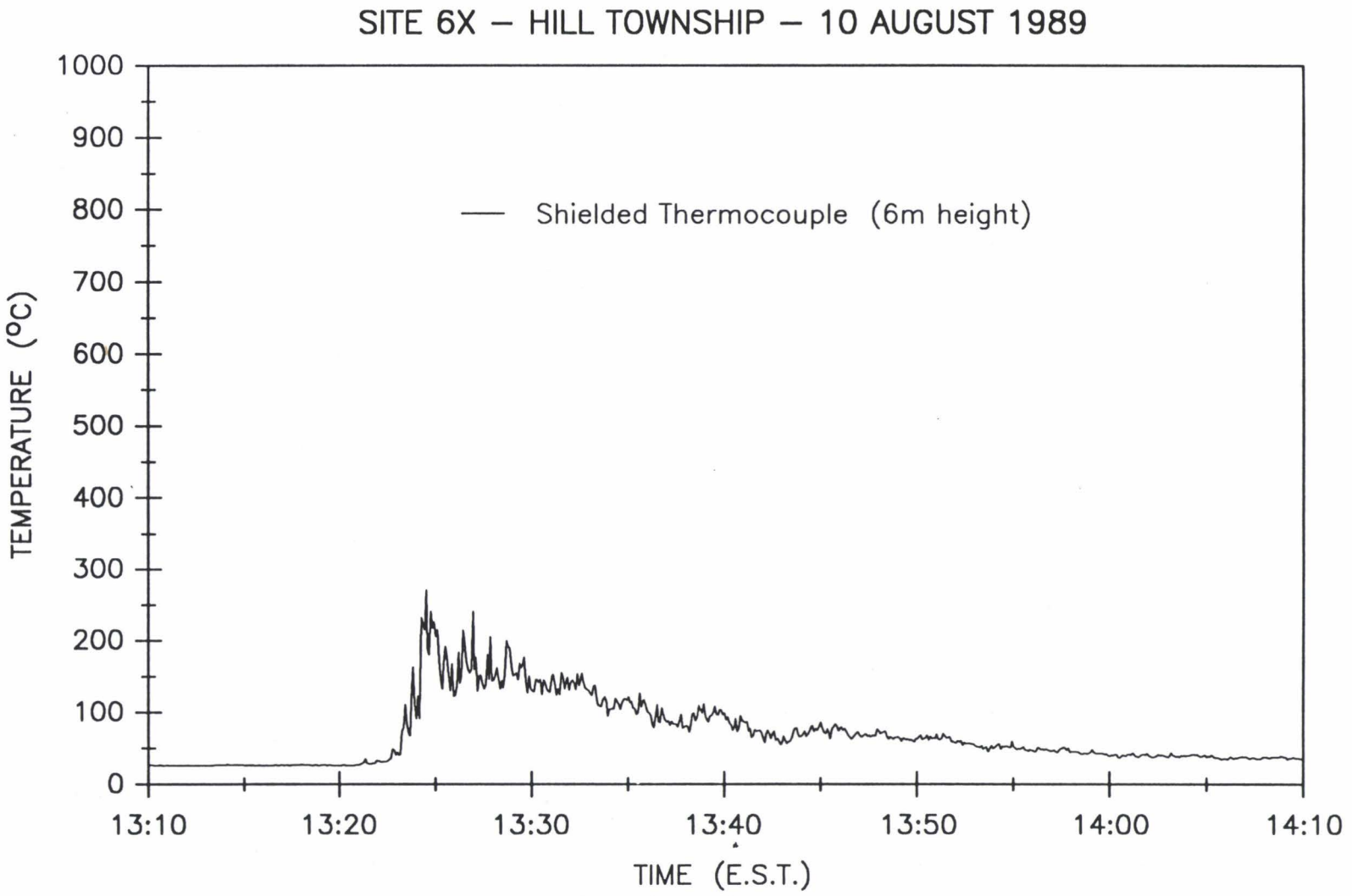

SITE 5C – HILL TOWNSHIP FIRE – 10 AUGUST 1989
Shielded Thermocouple (6m height)
TEMPERATURE (°C)
1000
900
800
700
600
500
400
300
200
100
0
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)

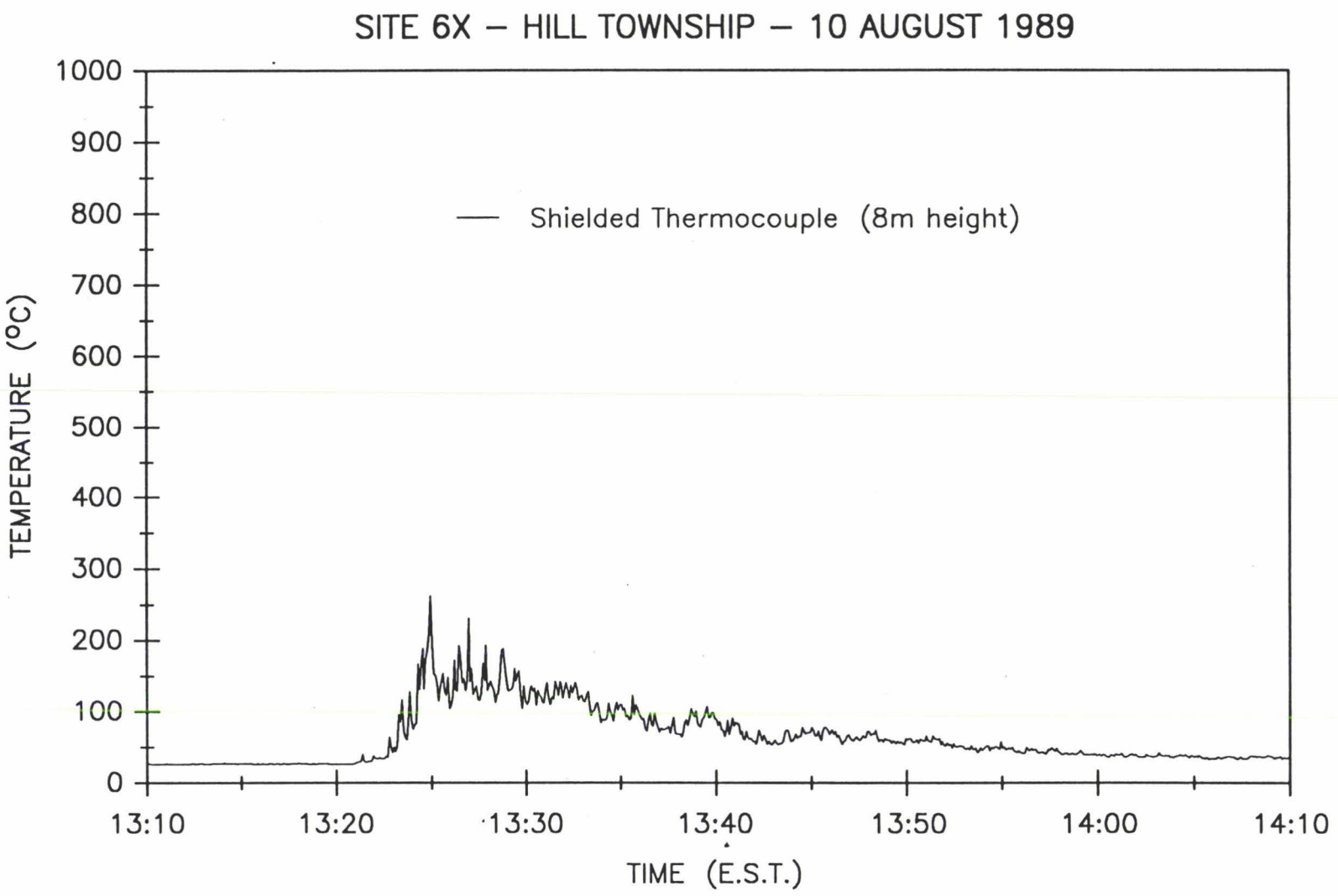

SITE 5C – HILL TOWNSHIP FIRE – 10 AUGUST 1989
Shielded Thermocouple (8m height)
TEMPERATURE (°C)
1000
900
800
700
600
500
400
300
200
100
0
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)

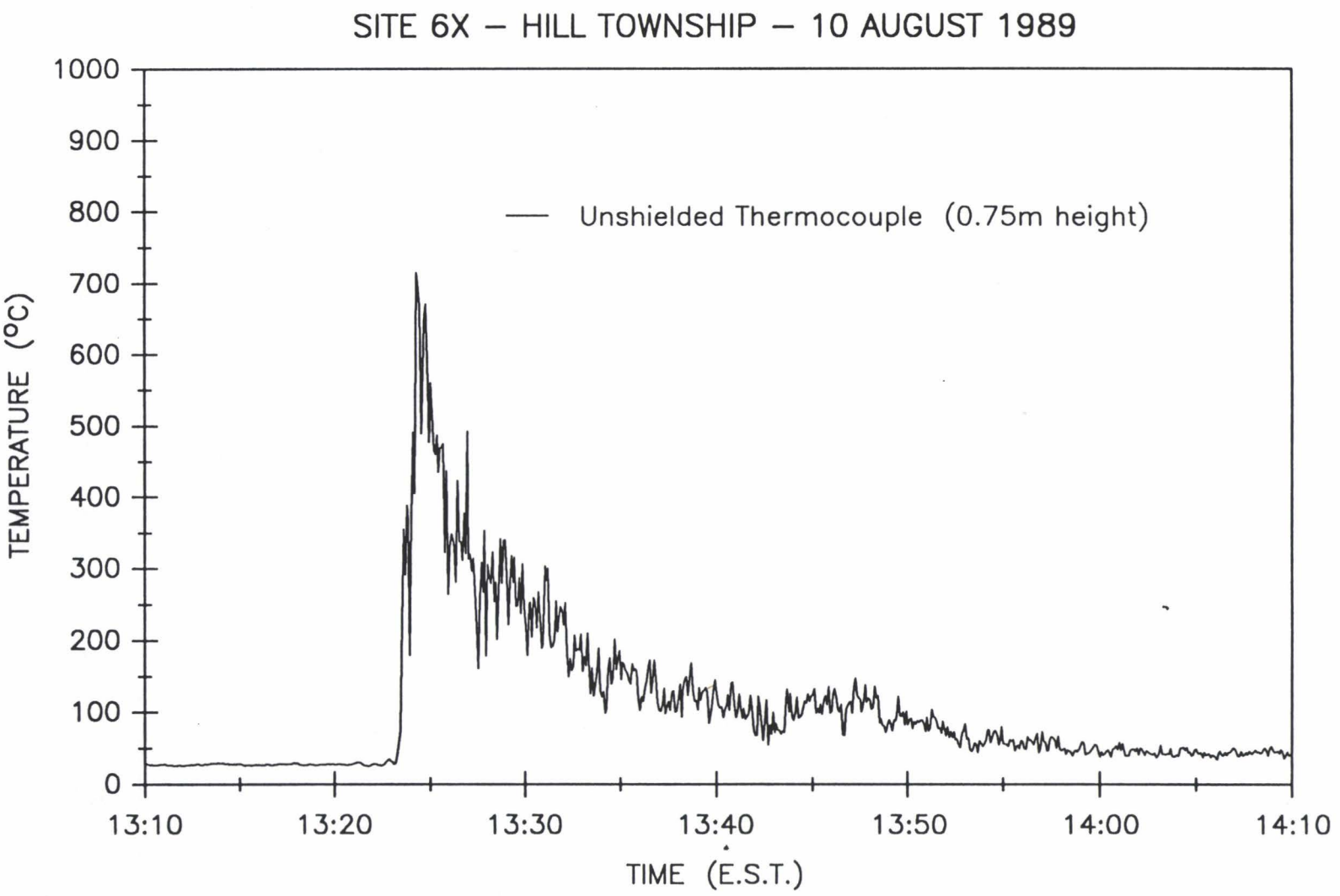

SITE 6X – HILL TOWNSHIP – 10 AUGUST 1989
Shielded Thermocouple (0.75m height)
TEMPERATURE (°C)
1000
900
800
700
600
500
400
300
200
100
0
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)

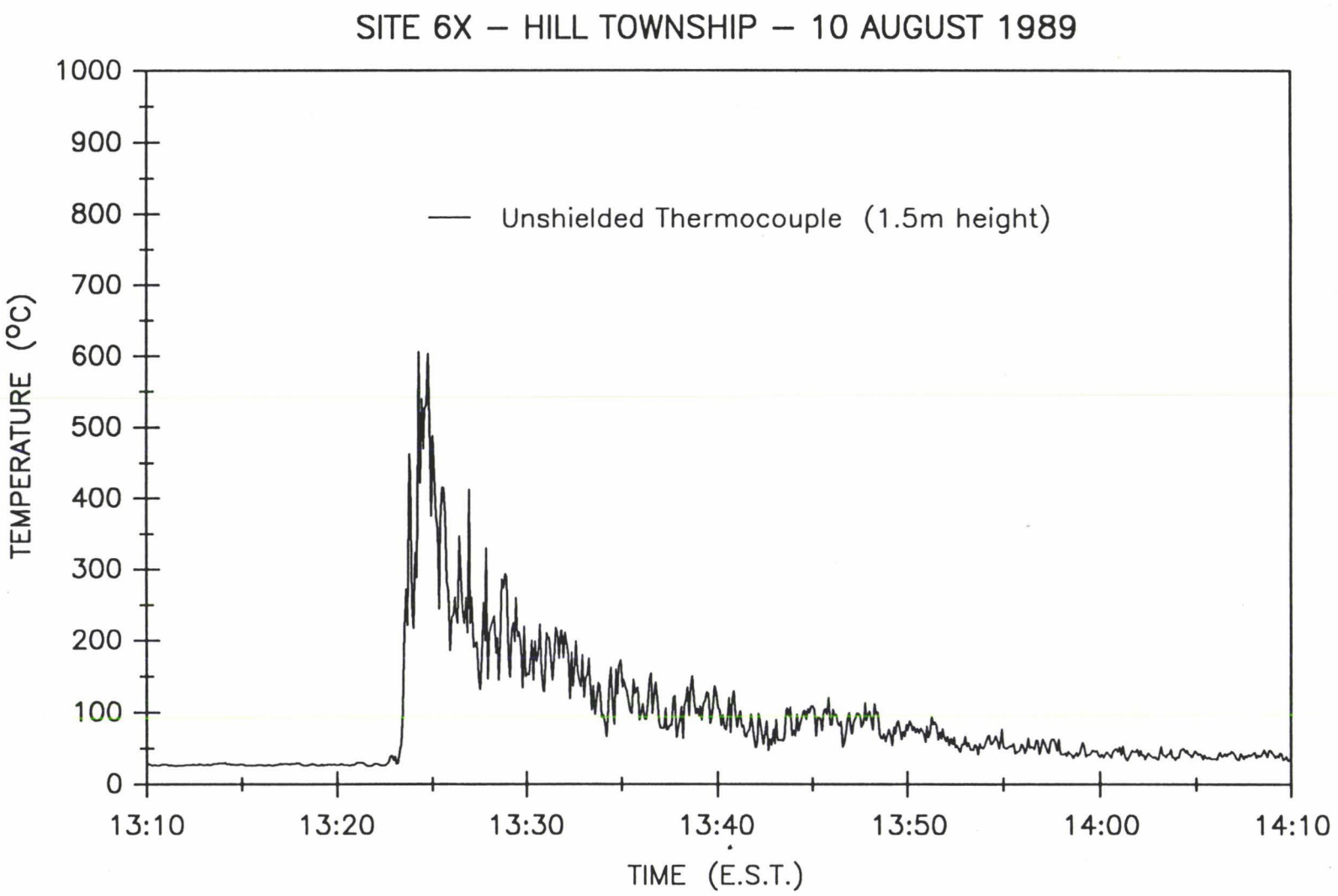

SITE 6X – HILL TOWNSHIP – 10 AUGUST 1989
Shielded Thermocouple (1.5m height)
TEMPERATURE (°C)
1000
900
800
700
600
500
400
300
200
100
0
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)

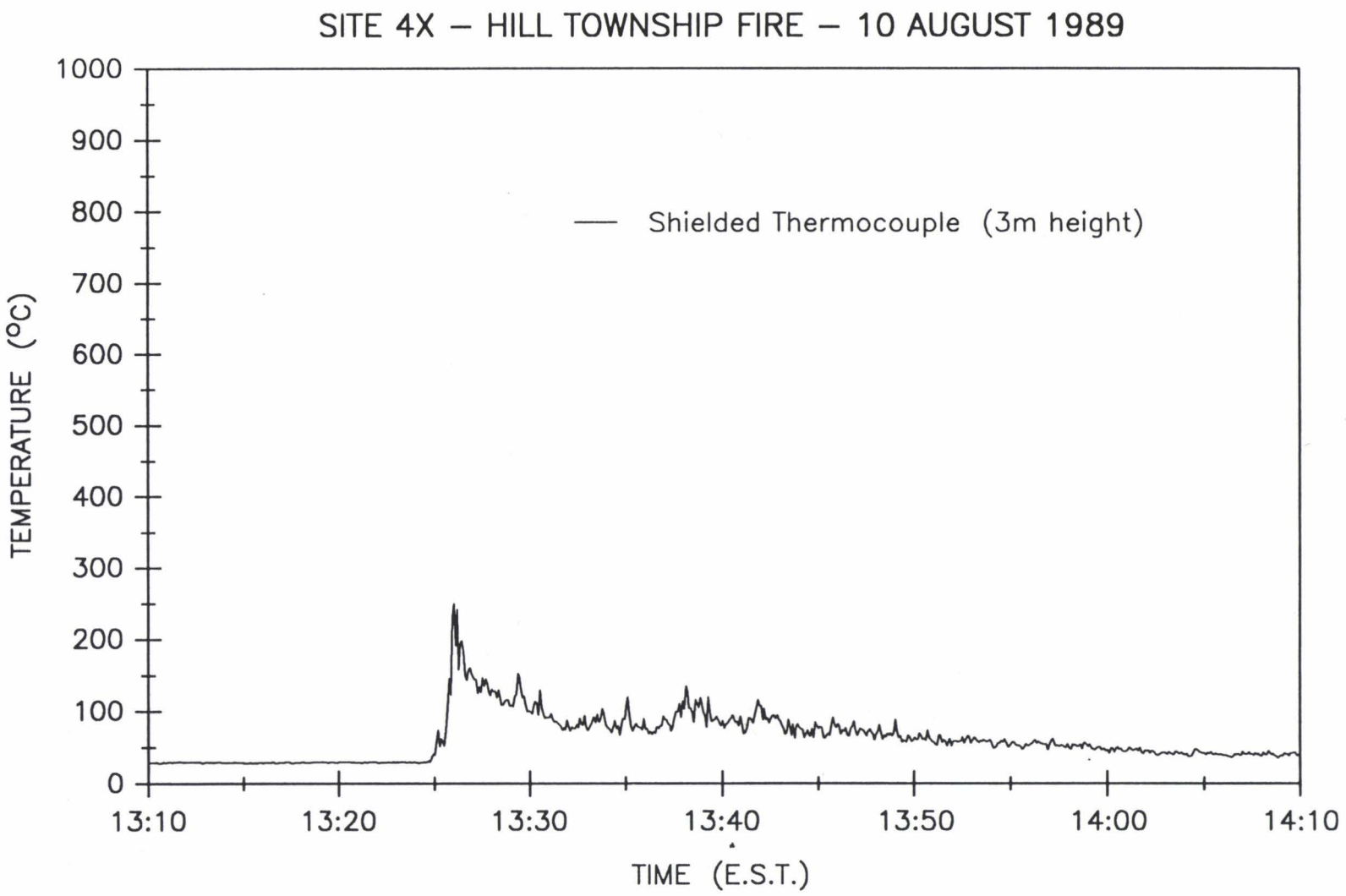

SITE 6X – HILL TOWNSHIP – 10 AUGUST 1989
Shielded Thermocouple (3m height)
TEMPERATURE (°C)
1000
900
800
700
600
500
400
300
200
100
0
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)

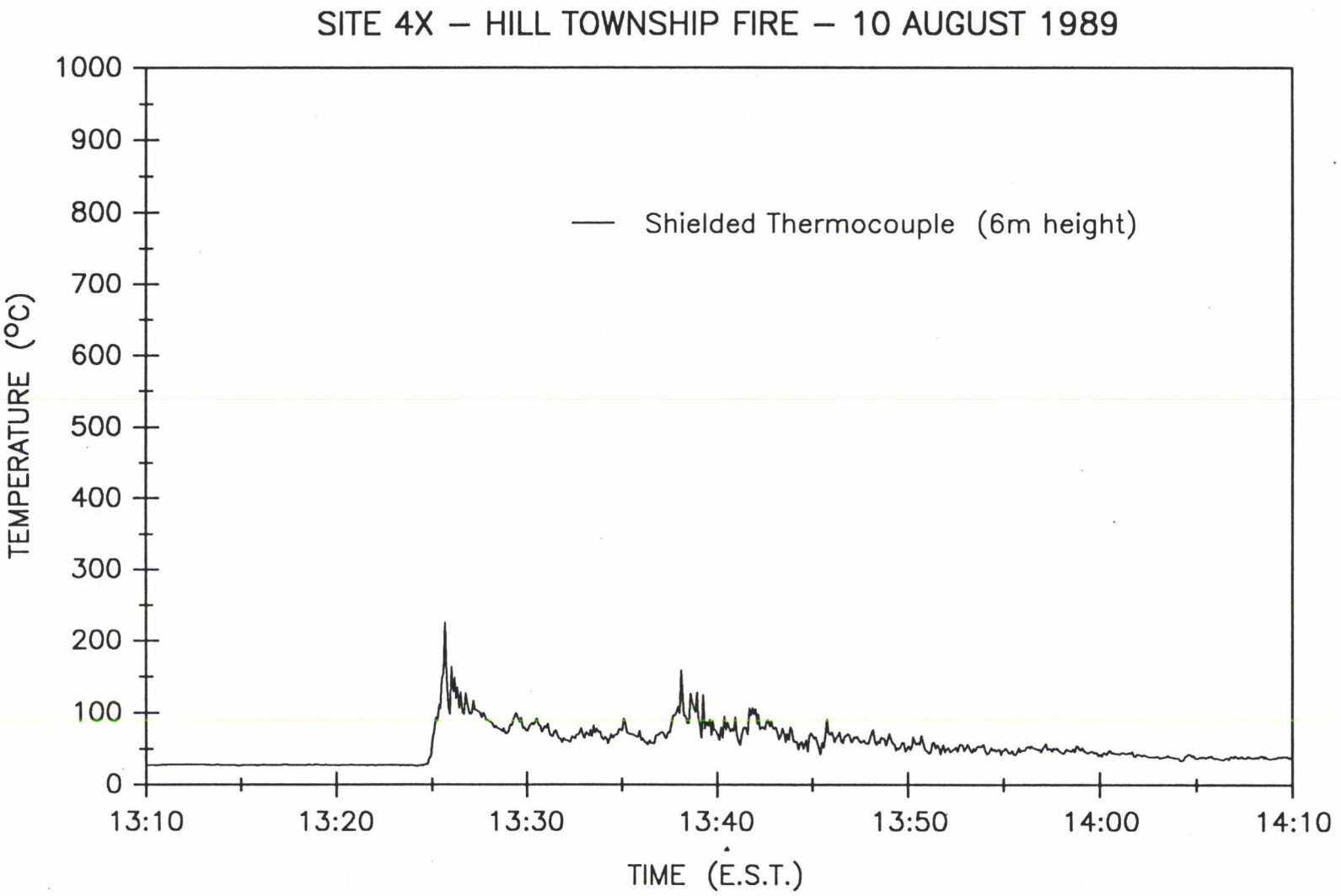

SITE 6X – HILL TOWNSHIP – 10 AUGUST 1989
Shielded Thermocouple (6m height)
TEMPERATURE (°C)
1000
900
800
700
600
500
400
300
200
100
0
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)

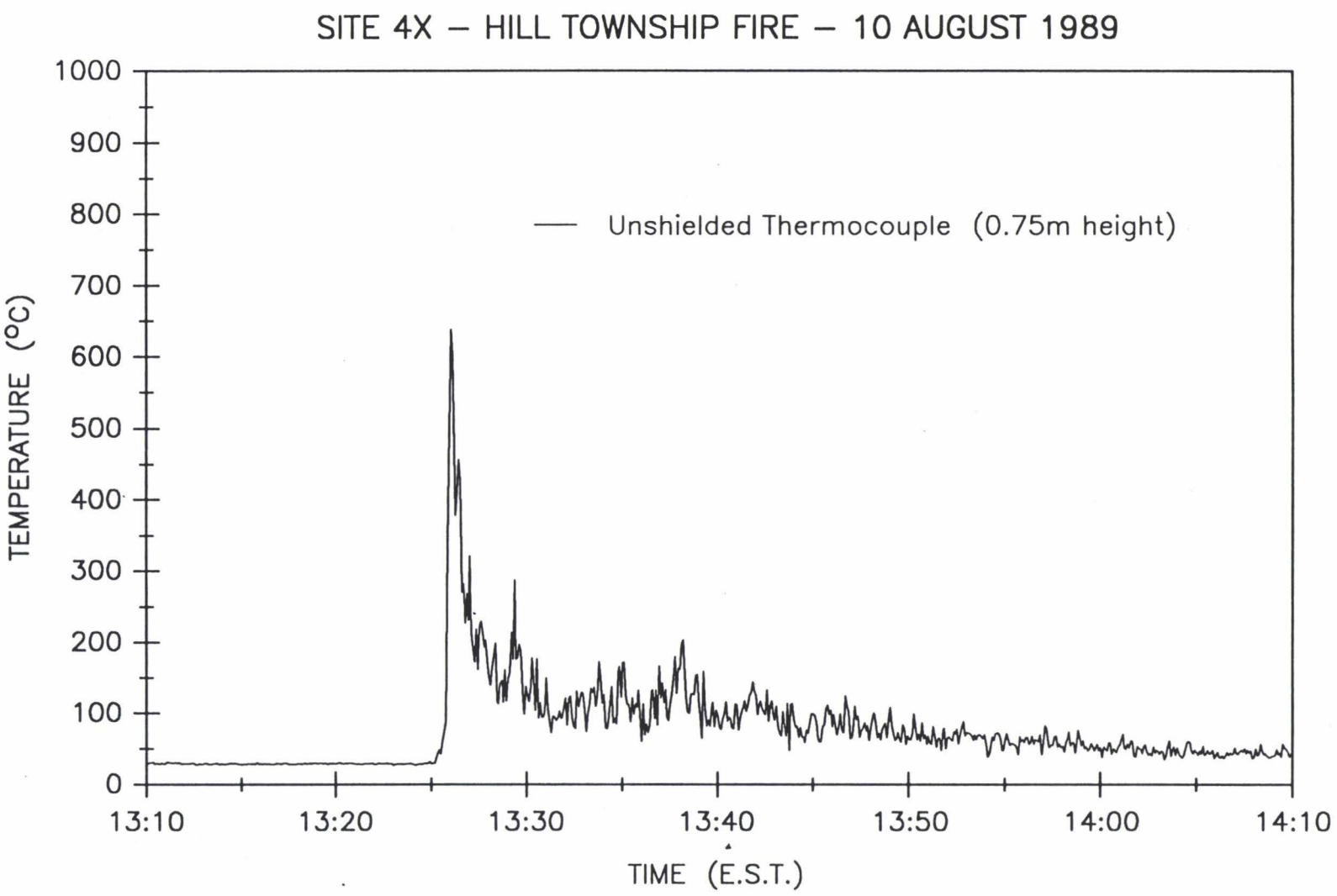

SITE 6X – HILL TOWNSHIP – 10 AUGUST 1989
Shielded Thermocouple (8m height)
TEMPERATURE (°C)
1000
900
800
700
600
500
400
300
200
100
0
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)

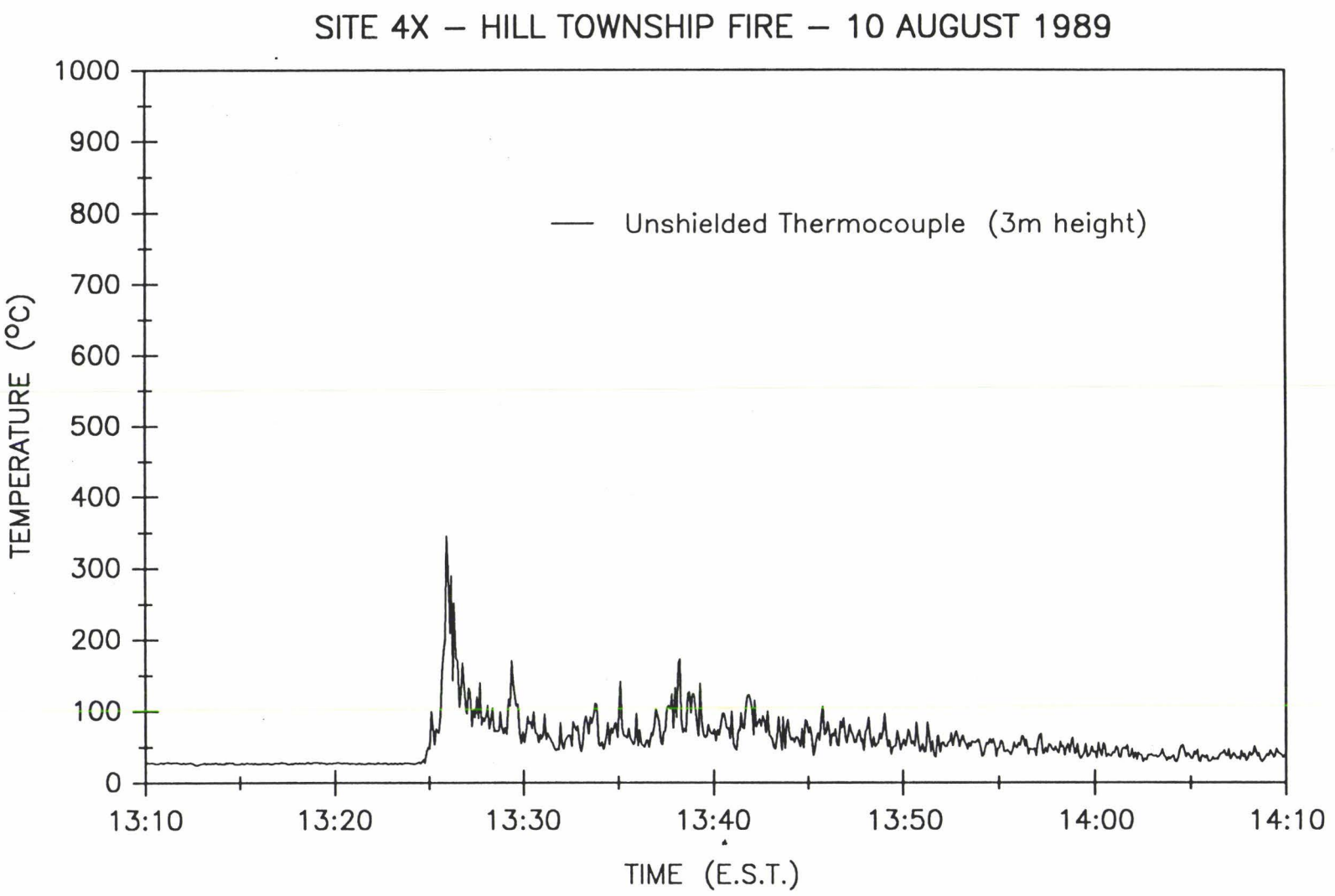

SITE 6X – HILL TOWNSHIP – 10 AUGUST 1989
Unshielded Thermocouple (0.75m height)
TEMPERATURE (°C)
1000
900
800
700
600
500
400
300
200
100
0
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)

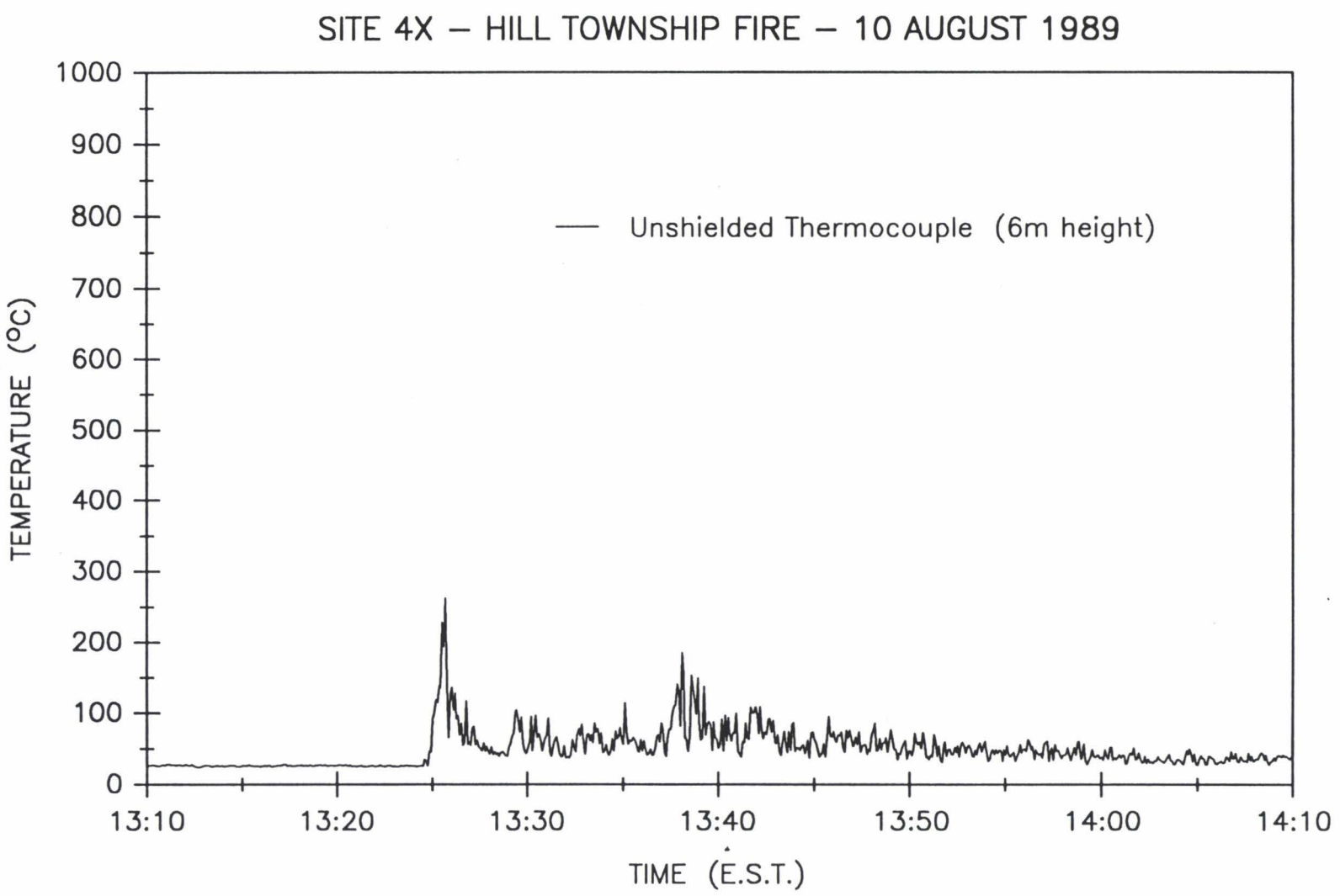

SITE 6X – HILL TOWNSHIP – 10 AUGUST 1989
Unshielded Thermocouple (1.5m height)
TEMPERATURE (°C)
1000
900
800
700
600
500
400
300
200
100
0
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)

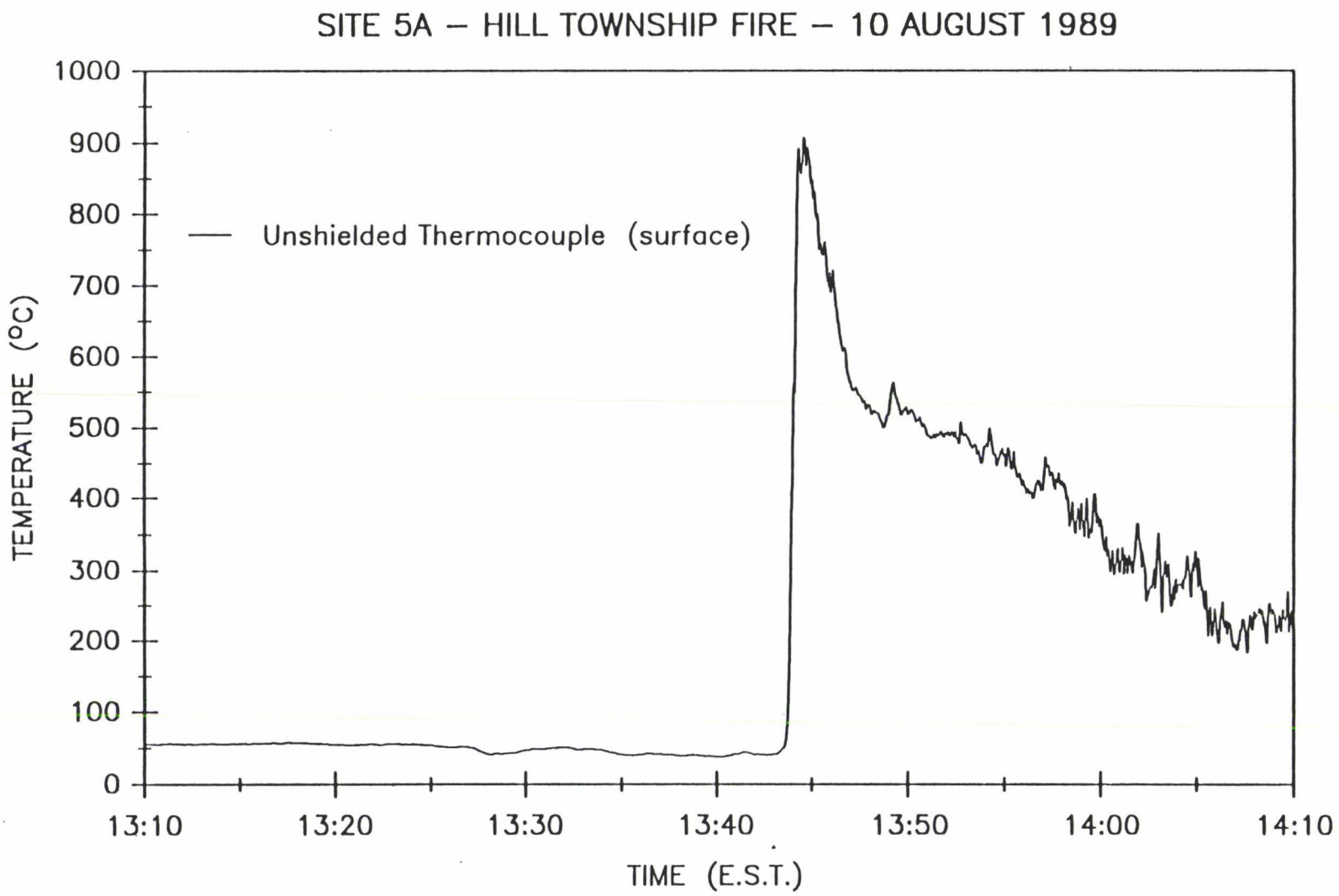

SITE 4X – HILL TOWNSHIP FIRE – 10 AUGUST 1989
1000
900
800
700
600
500
400
300
200
100
0
TEMPERATURE (°C)
Shielded Thermocouple (3m height)
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)

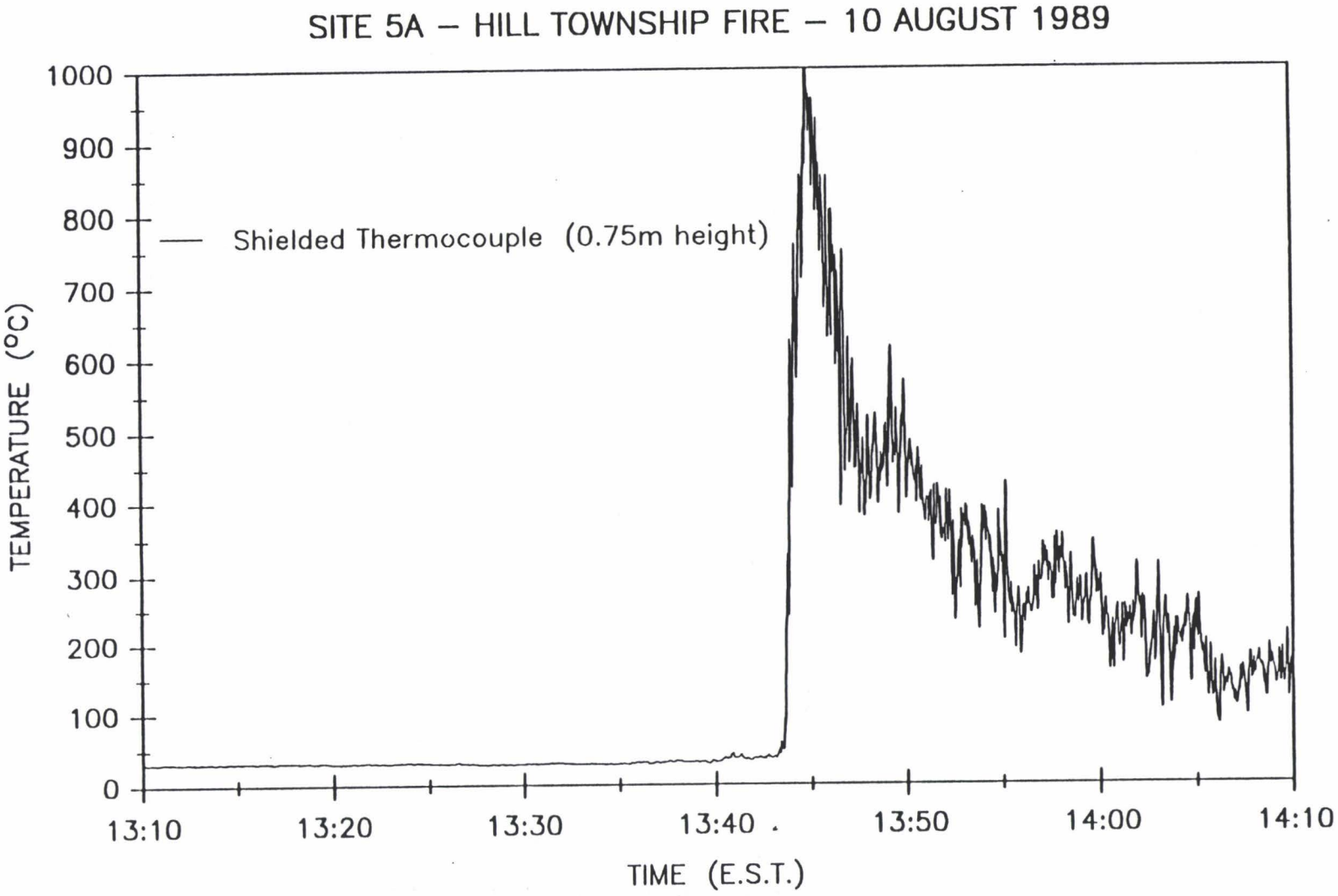

SITE 4X – HILL TOWNSHIP FIRE – 10 AUGUST 1989
1000
900
800
700
600
500
400
300
200
100
0
TEMPERATURE (°C)
Shielded Thermocouple (6m height)
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)

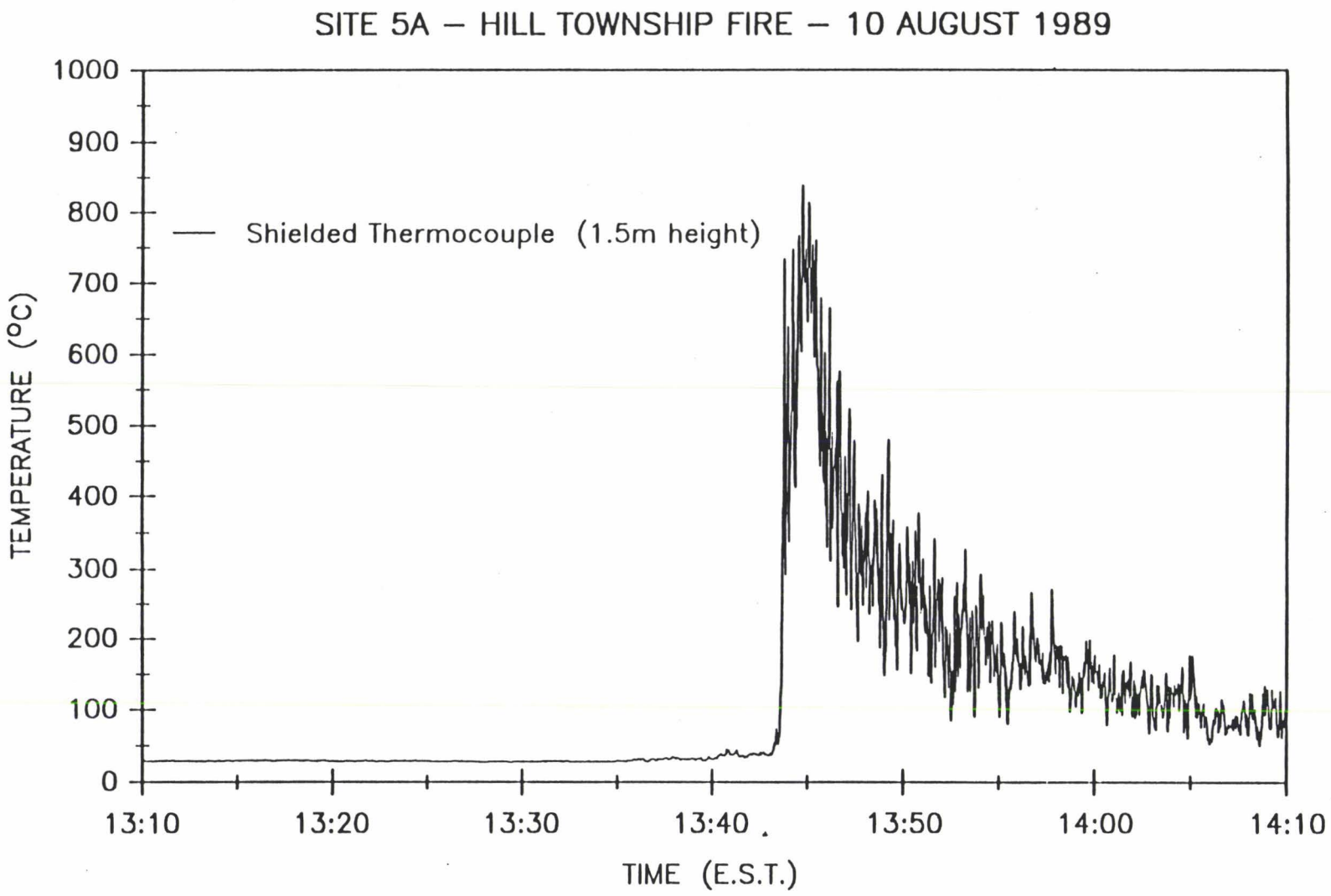

SITE 4X – HILL TOWNSHIP FIRE – 10 AUGUST 1989
Unshielded Thermocouple (0.75m height)
TEMPERATURE (°C)
1000
900
800
700
600
500
400
300
200
100
0
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)

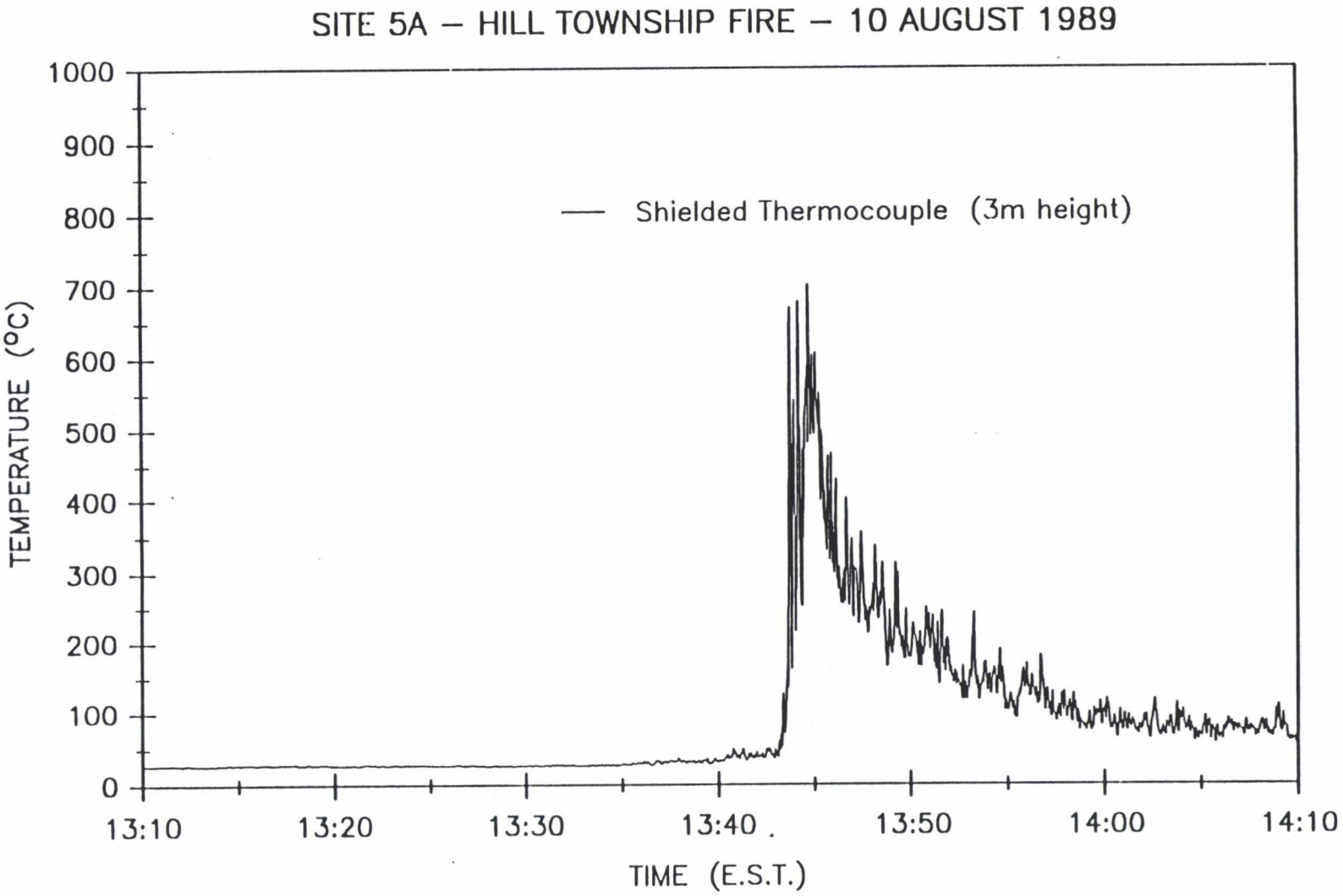

SITE 4X – HILL TOWNSHIP FIRE – 10 AUGUST 1989
Unshielded Thermocouple (3m height)
TEMPERATURE (°C)
1000
900
800
700
600
500
400
300
200
100
0
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)

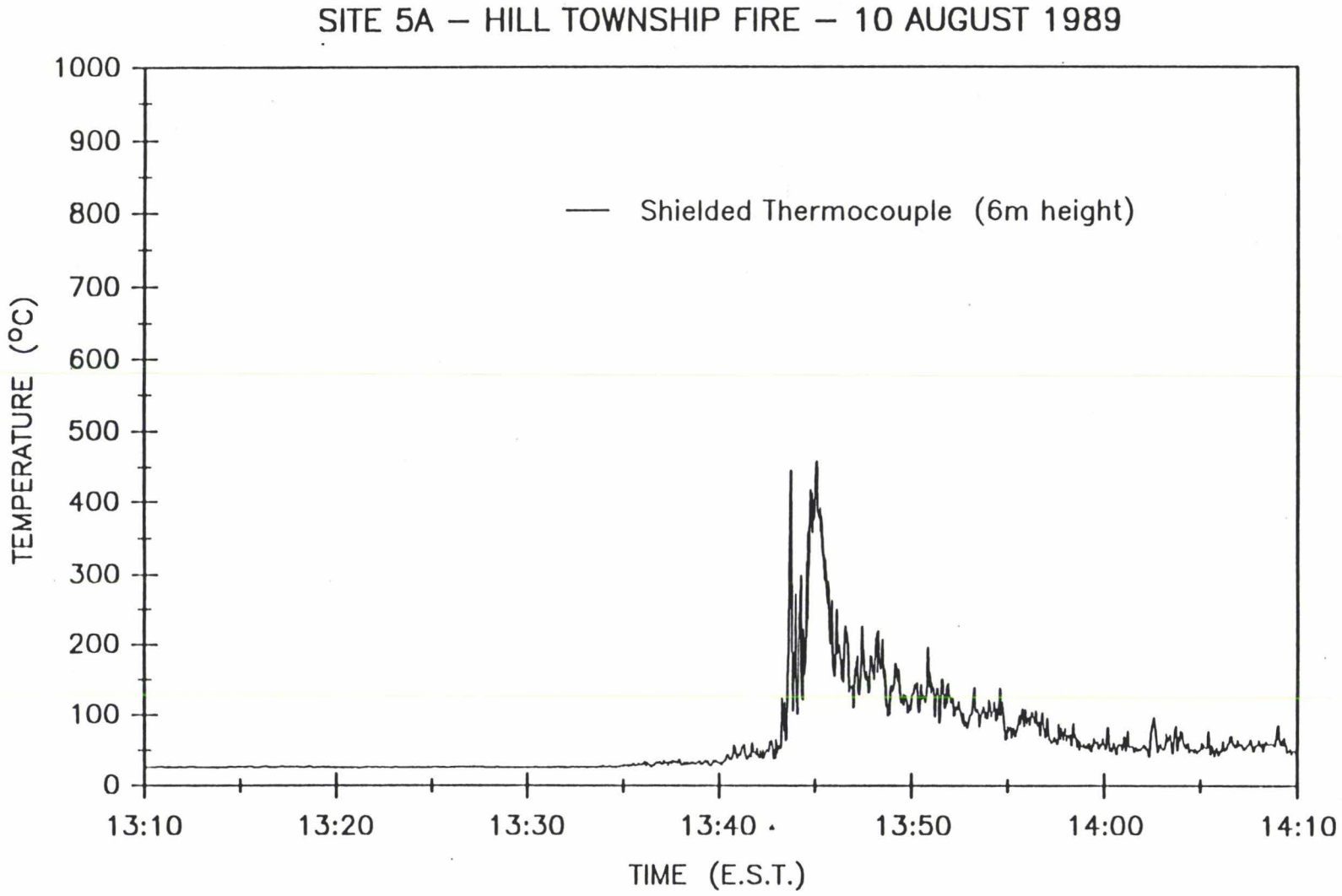

SITE 4X – HILL TOWNSHIP FIRE – 10 AUGUST 1989
1000
900
800
700
600
500
400
300
200
100
0
TEMPERATURE (°C)
Unshielded Thermocouple (6m height)
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)

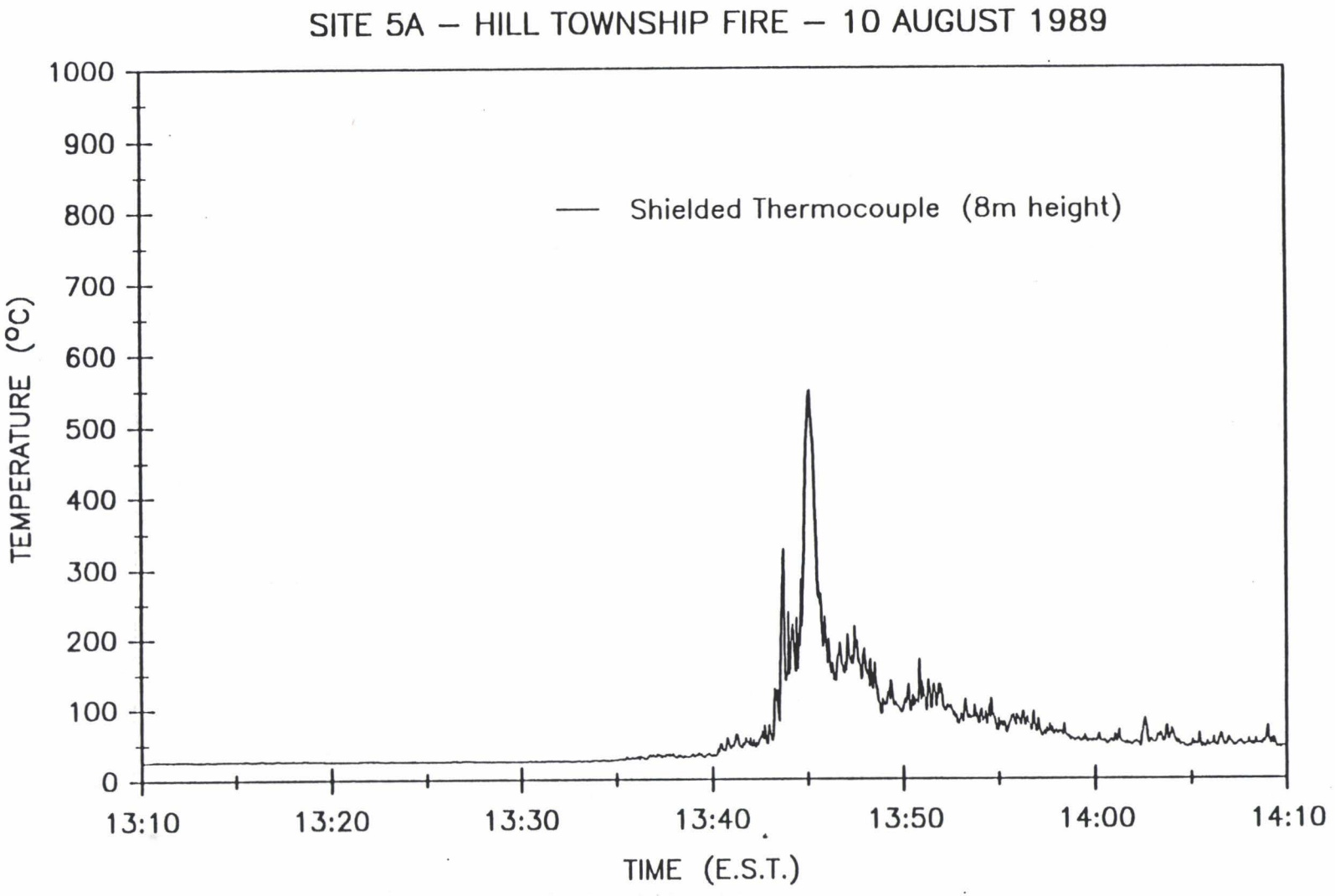

SITE 5A – HILL TOWNSHIP FIRE – 10 AUGUST 1989
Unshielded Thermocouple (surface)
TEMPERATURE (°C)
1000
900
800
700
600
500
400
300
200
100
0
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)

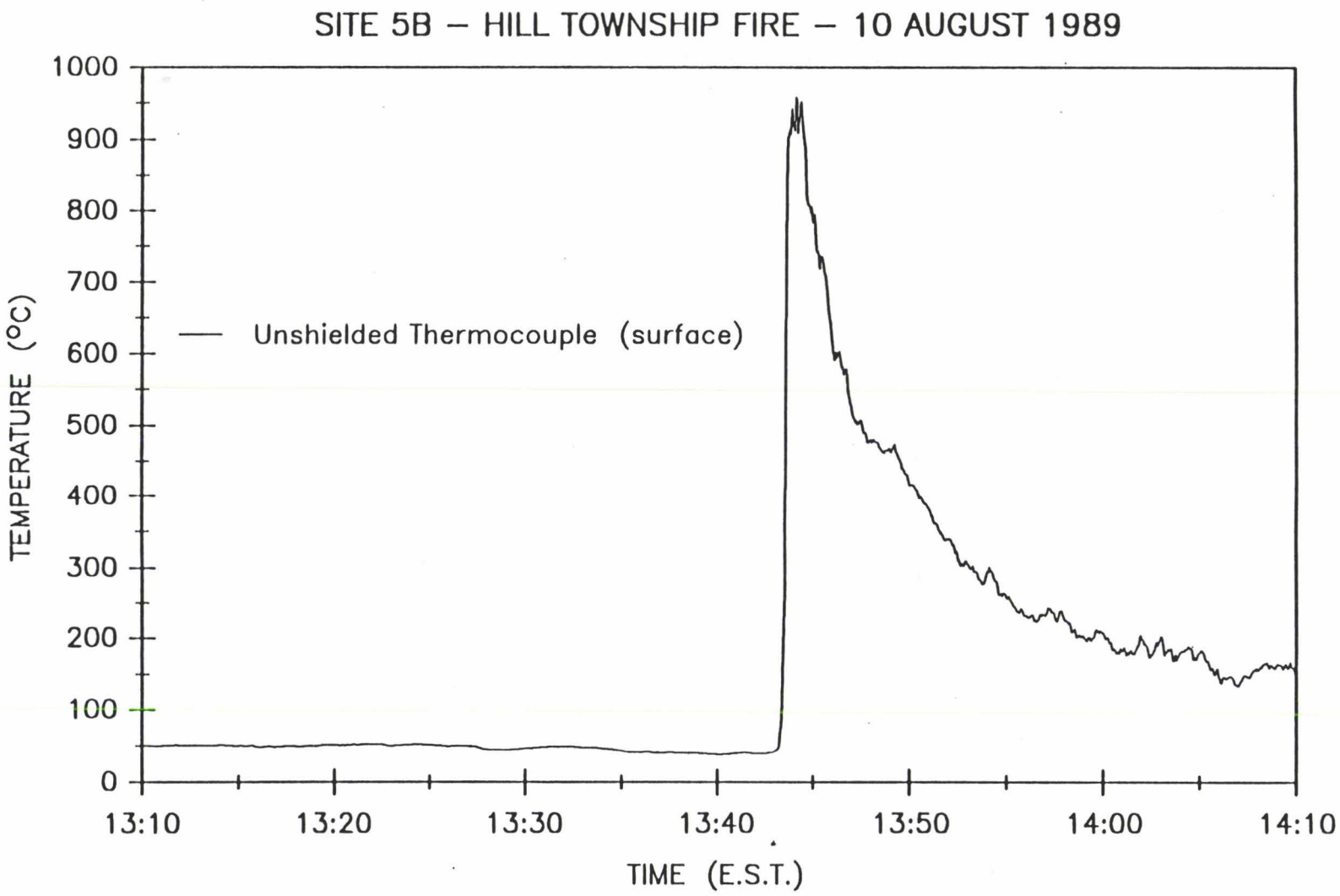

SITE 5A – HILL TOWNSHIP FIRE – 10 AUGUST 1989
Shielded Thermocouple (0.75m height)
TEMPERATURE (°C)
1000
900
800
700
600
500
400
300
200
100
0
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)

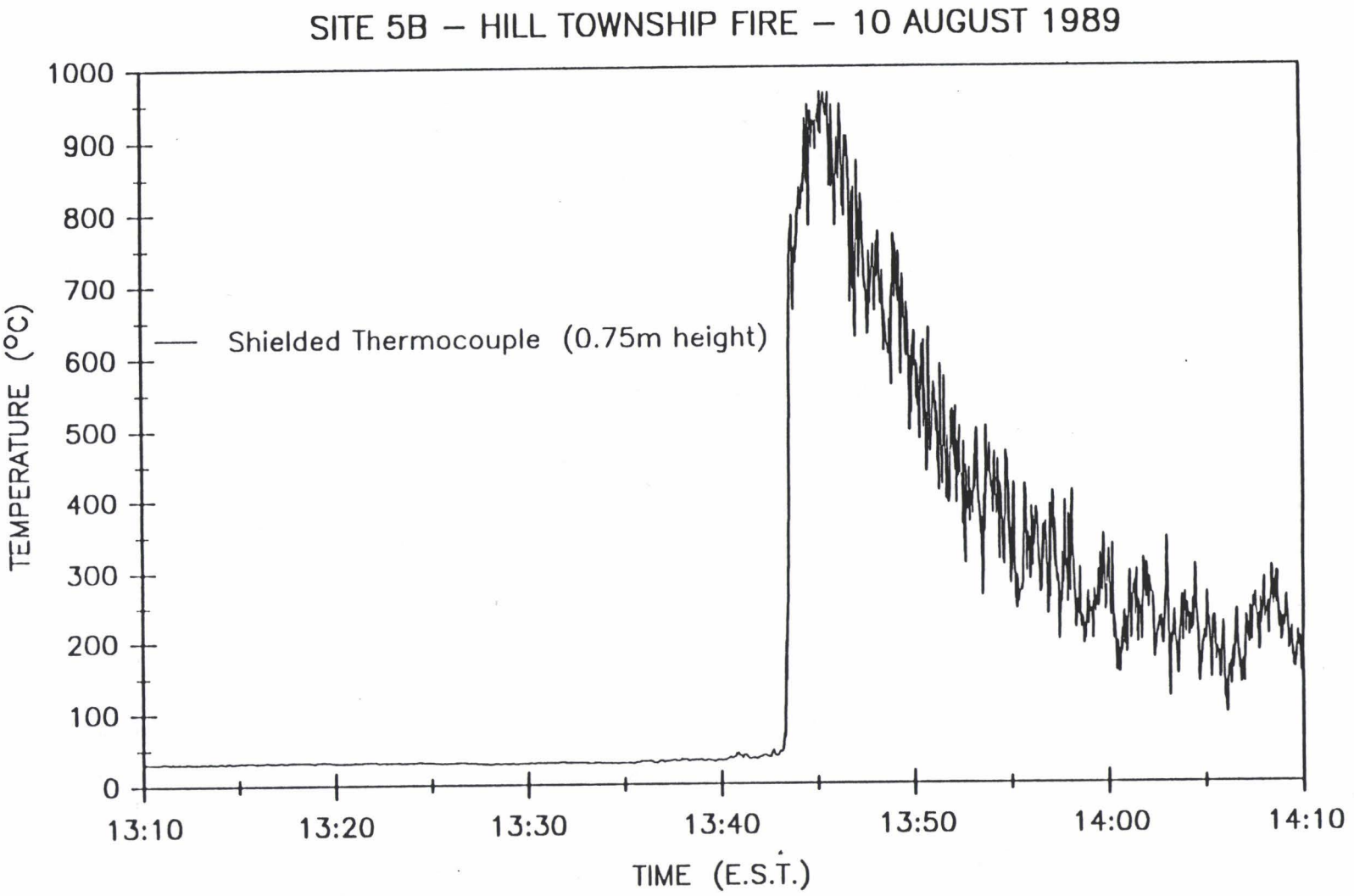

SITE 5A – HILL TOWNSHIP FIRE – 10 AUGUST 1989
Shielded Thermocouple (1.5m height)
TEMPERATURE (°C)
1000
900
800
700
600
500
400
300
200
100
0
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)

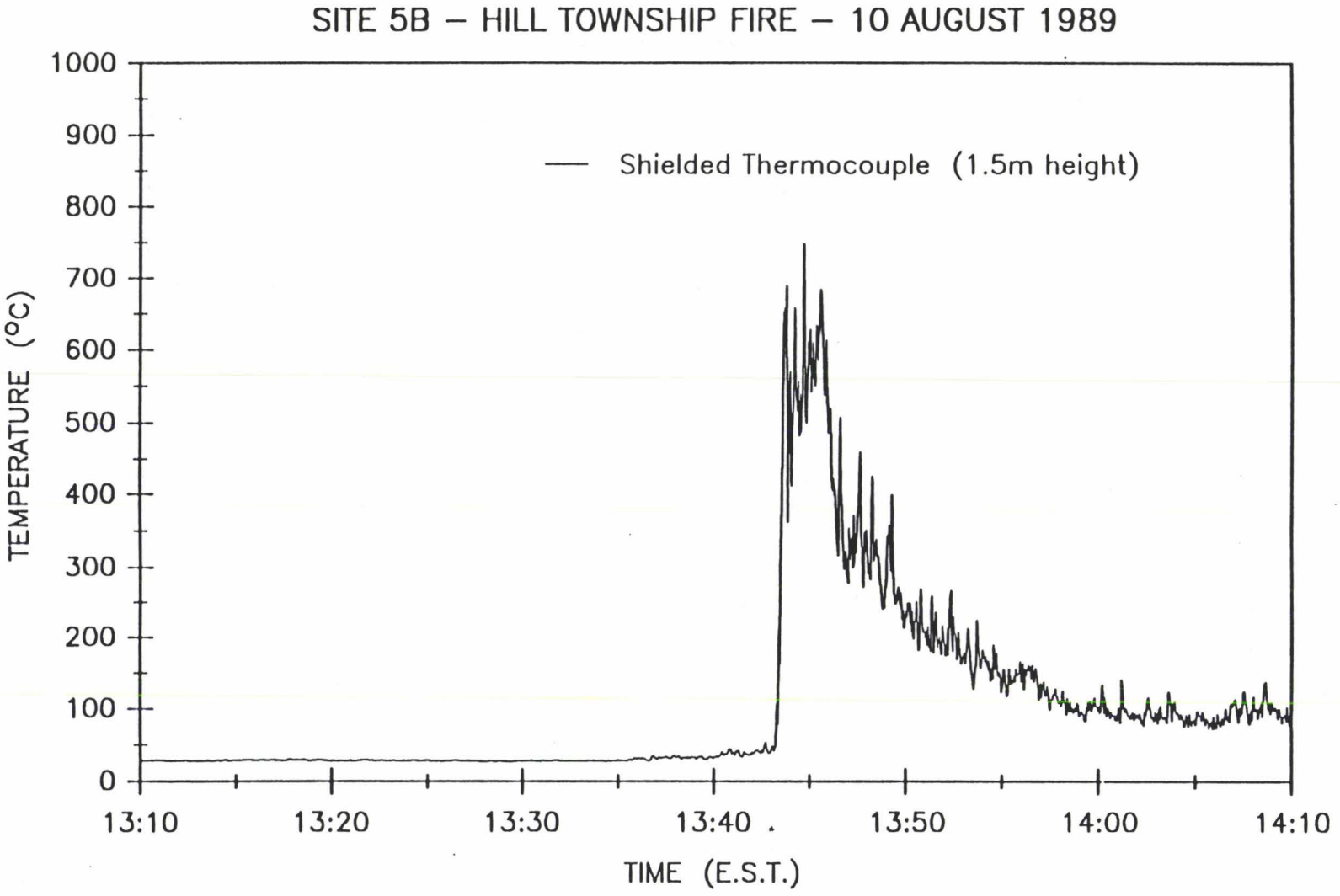

SITE 5A – HILL TOWNSHIP FIRE – 10 AUGUST 1989
Shielded Thermocouple (3m height)
TEMPERATURE (°C)
1000
900
800
700
600
500
400
300
200
100
0
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)

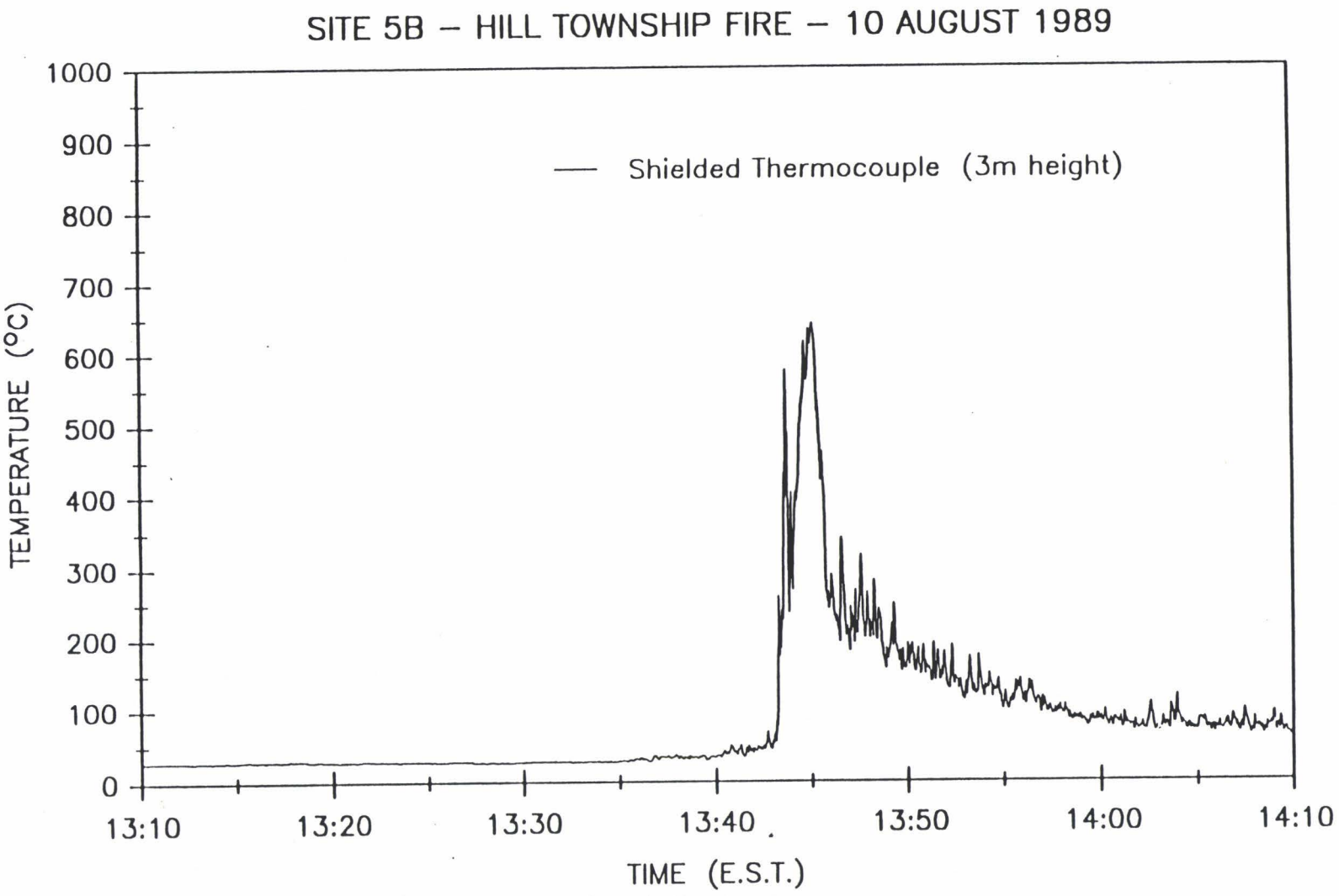

SITE 5A – HILL TOWNSHIP FIRE – 10 AUGUST 1989
Shielded Thermocouple (6m height)
TEMPERATURE (°C)
1000
900
800
700
600
500
400
300
200
100
0
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)

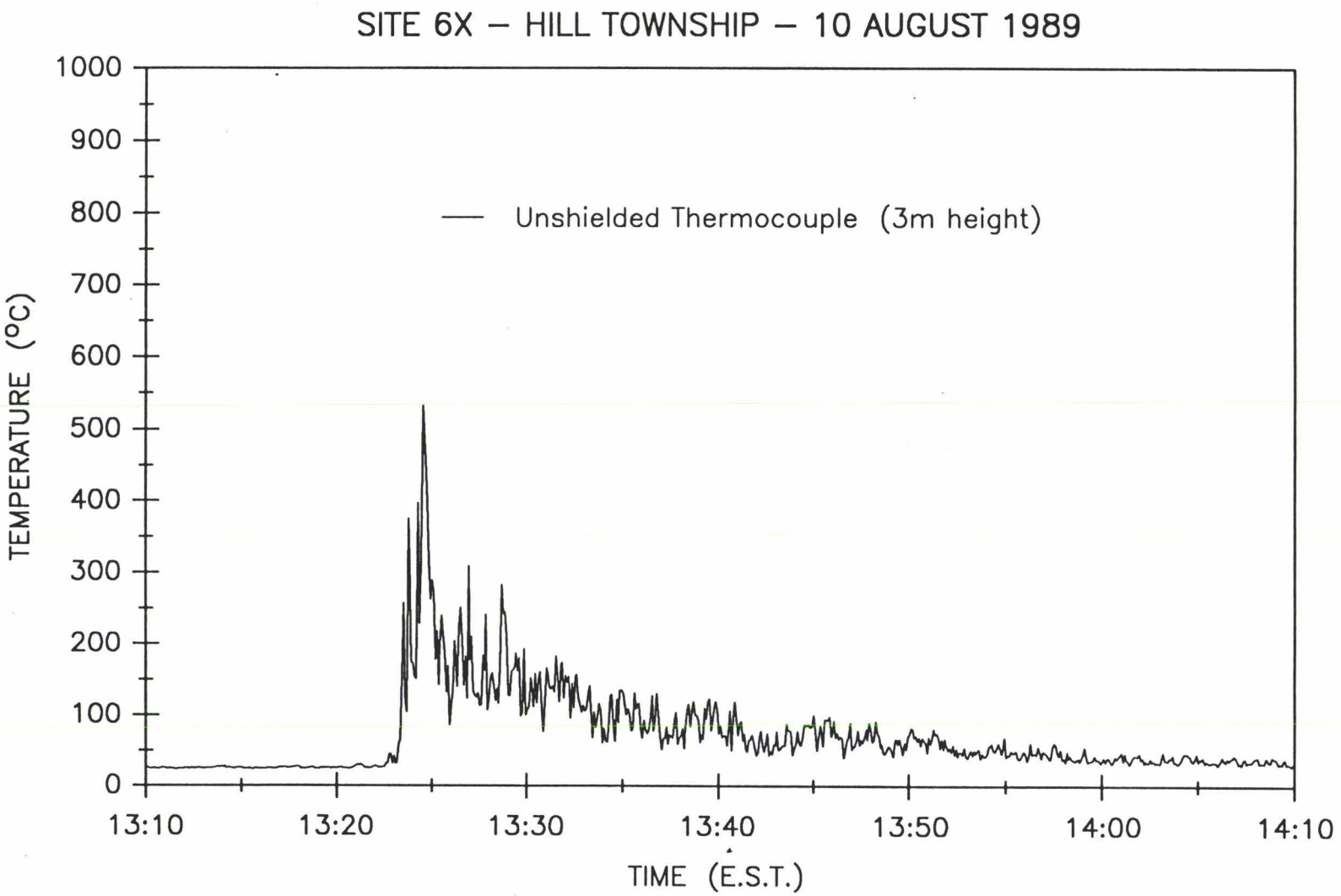

SITE 5A – HILL TOWNSHIP FIRE – 10 AUGUST 1989
Shielded Thermocouple (8m height)
TEMPERATURE (°C)
1000
900
800
700
600
500
400
300
200
100
0
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)

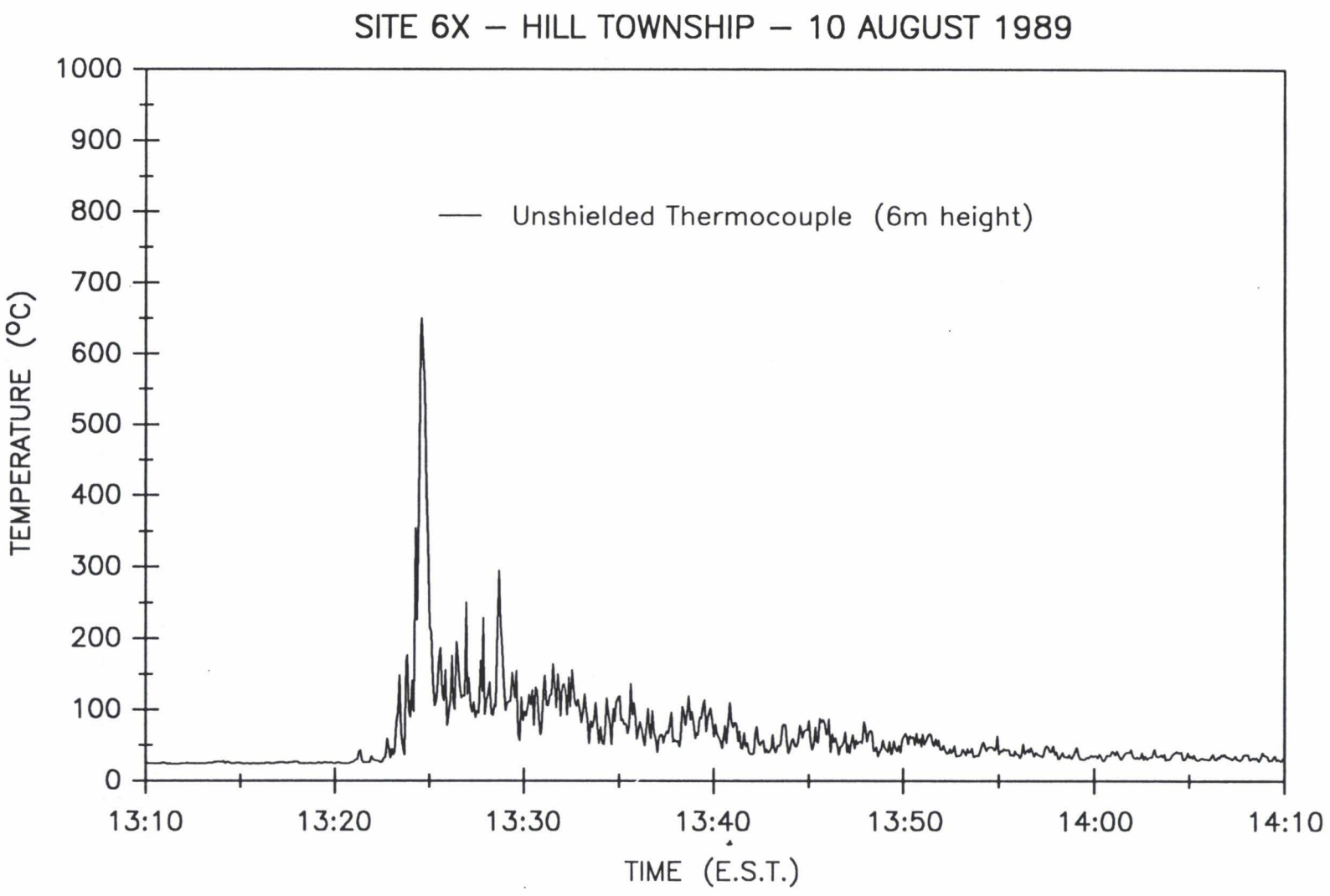

SITE 5B – HILL TOWNSHIP FIRE – 10 AUGUST 1989
TEMPERATURE (°C)
1000
900
800
700
600
500
400
300
200
100
0
Unshielded Thermocouple (surface)
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)

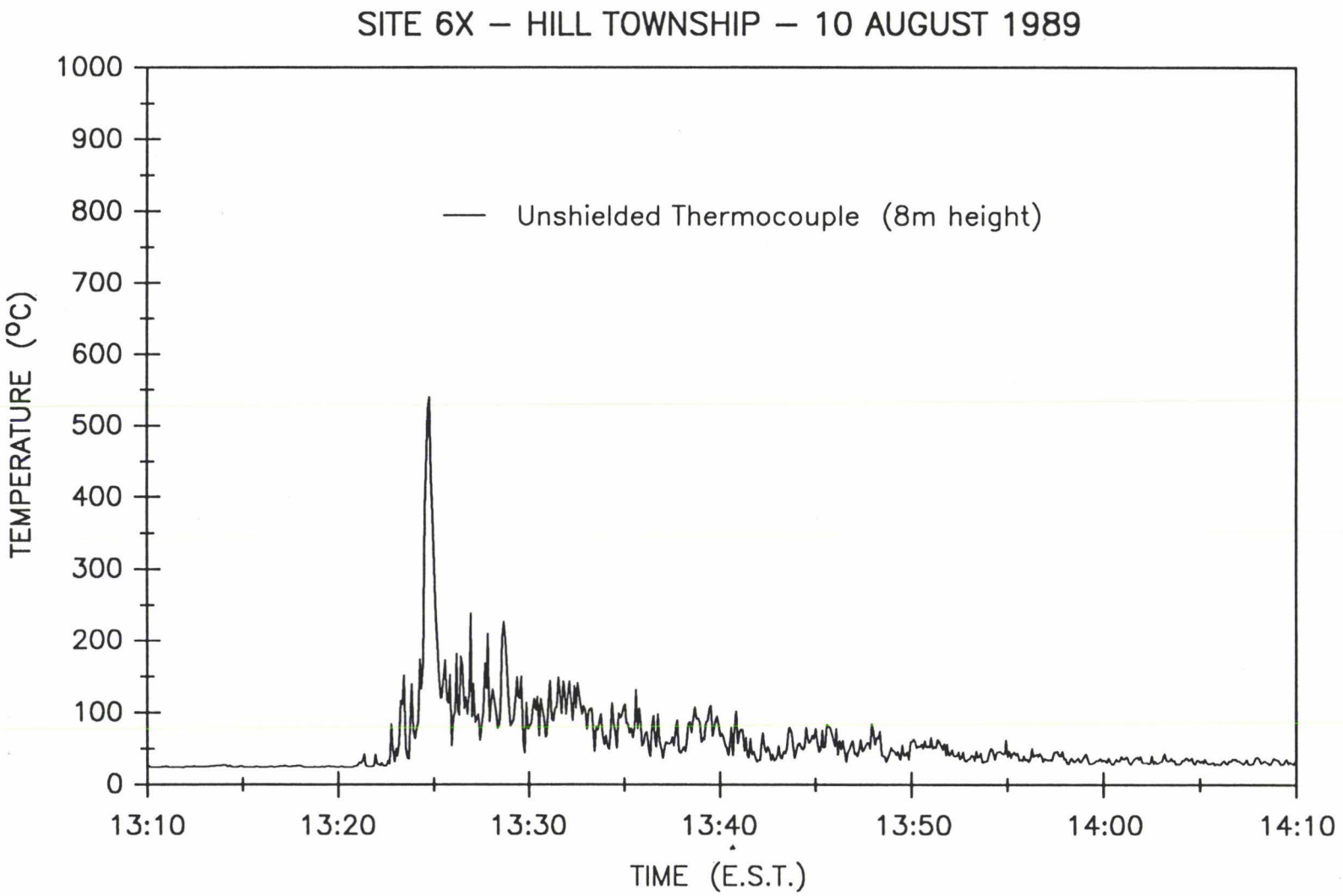

SITE 5B – HILL TOWNSHIP FIRE – 10 AUGUST 1989
1000
900
800
700
600
500
400
300
200
100
0
TEMPERATURE (°C)
Shielded Thermocouple (0.75m height)
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)

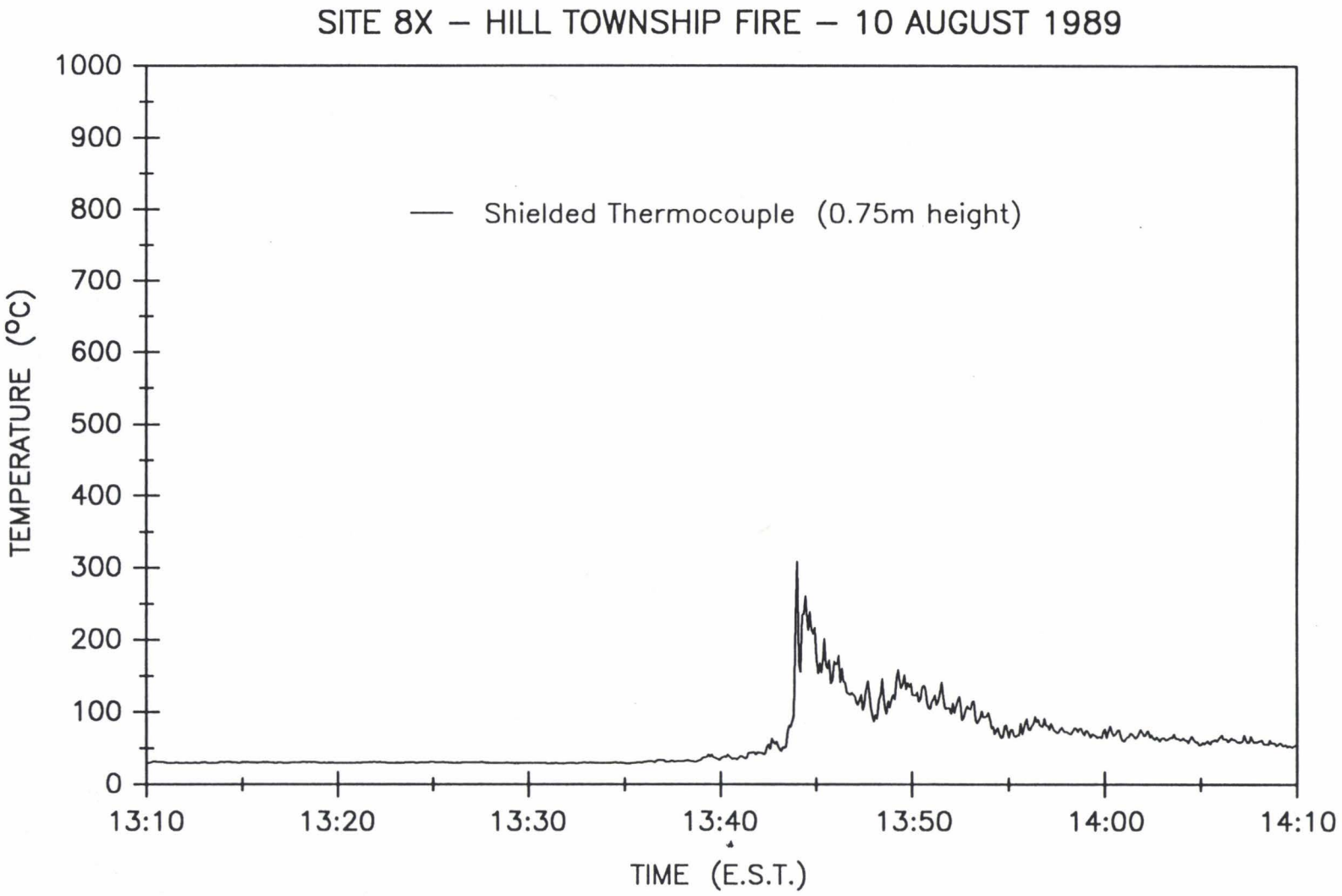

SITE 5B – HILL TOWNSHIP FIRE – 10 AUGUST 1989
Shielded Thermocouple (1.5m height)
TEMPERATURE (°C)
1000
900
800
700
600
500
400
300
200
100
0
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)

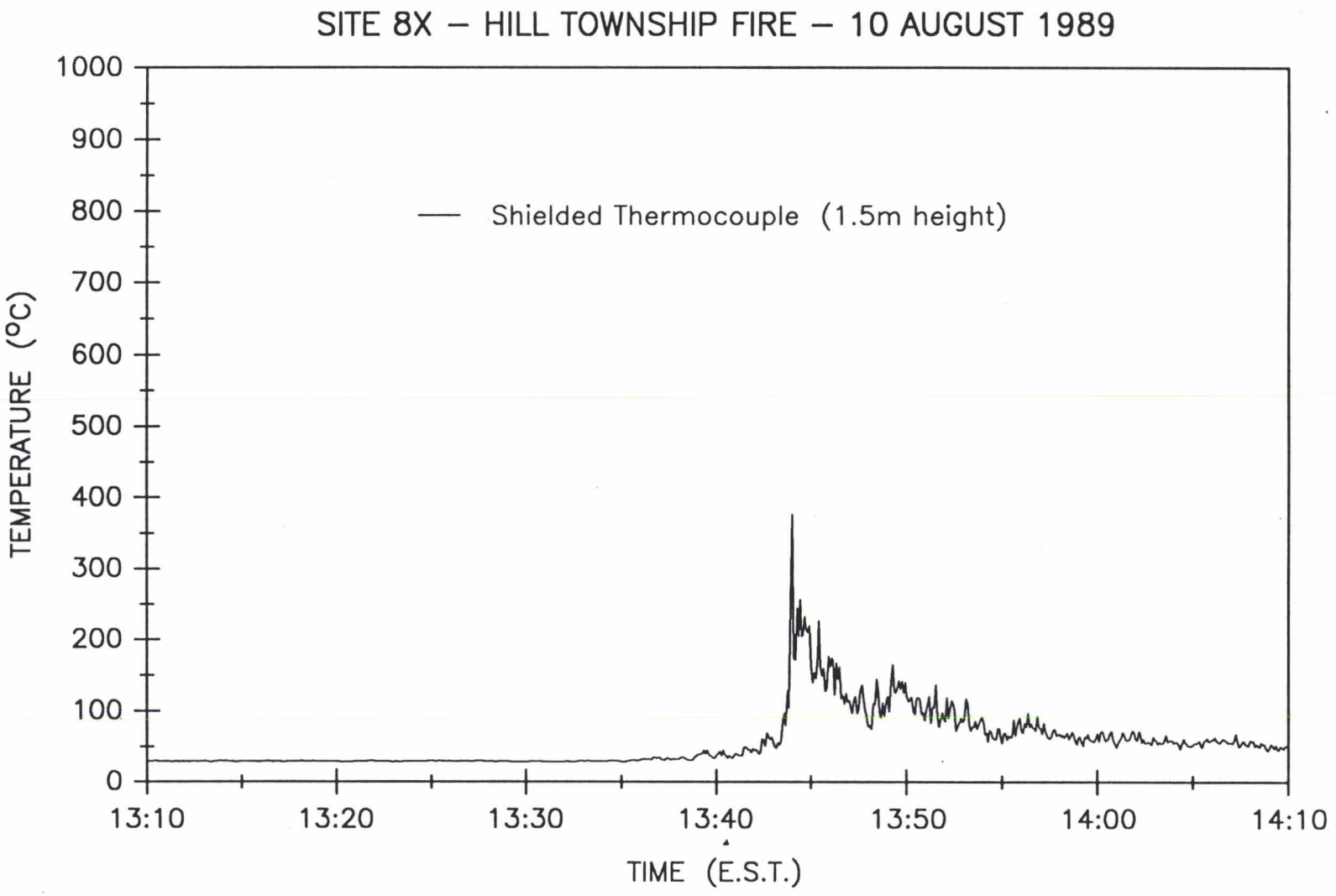

SITE 5B – HILL TOWNSHIP FIRE – 10 AUGUST 1989
Shielded Thermocouple (3m height)
TEMPERATURE (°C)
1000
900
800
700
600
500
400
300
200
100
0
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)

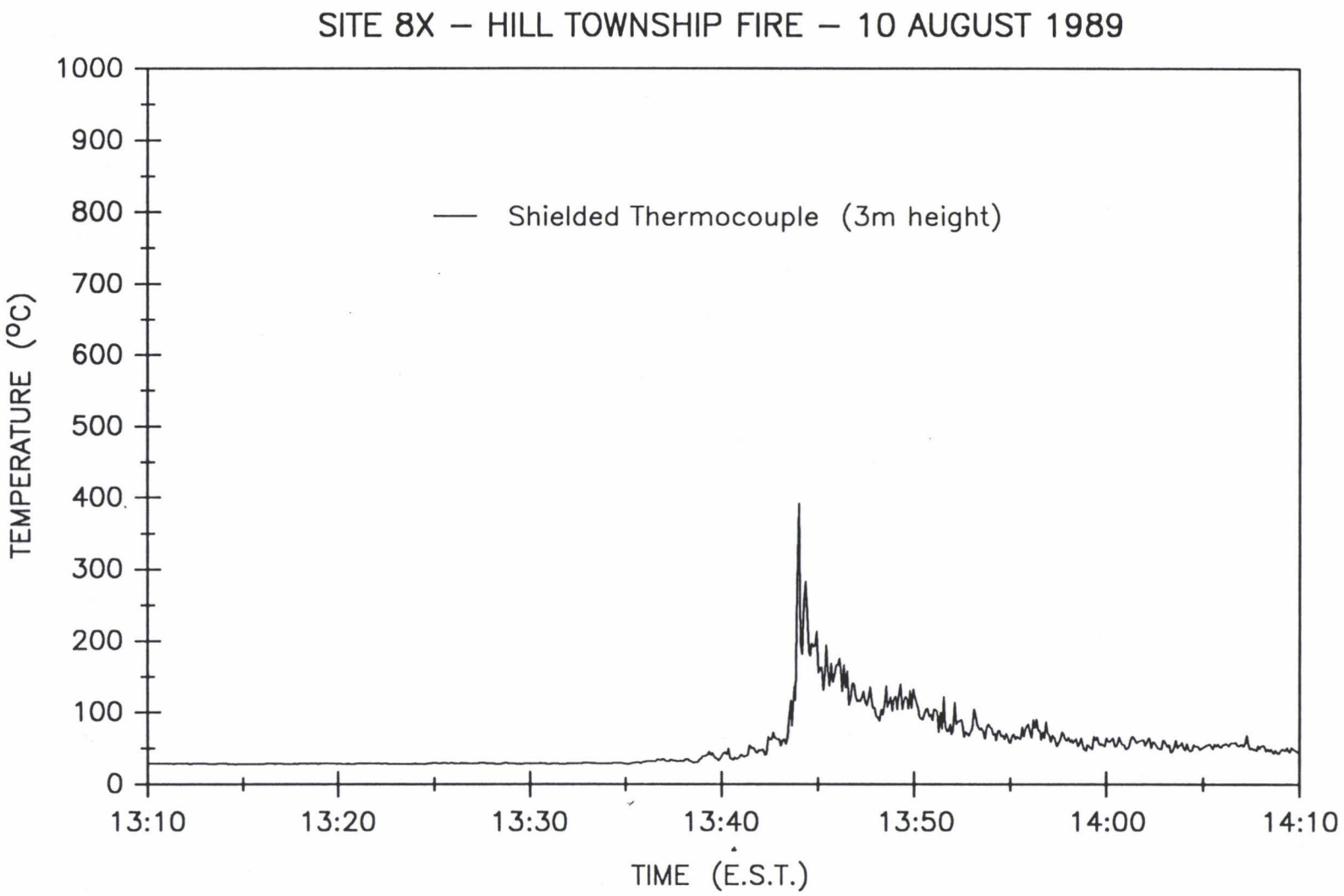

SITE 6X – HILL TOWNSHIP – 10 AUGUST 1989
Unshielded Thermocouple (3m height)
TEMPERATURE (°C)
1000
900
800
700
600
500
400
300
200
100
0
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)

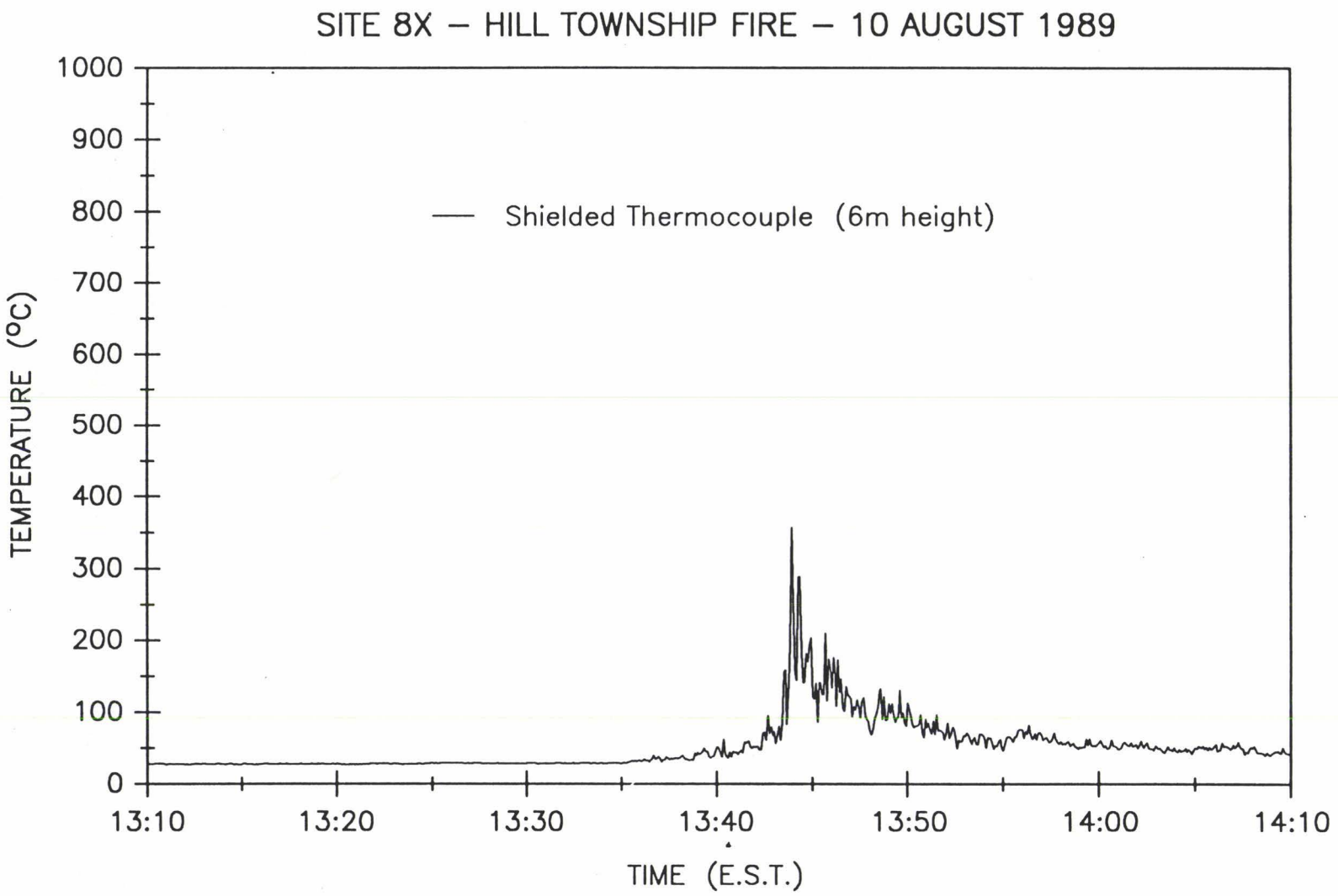

SITE 6X – HILL TOWNSHIP – 10 AUGUST 1989
Unshielded Thermocouple (6m height)
TEMPERATURE (°C)
1000
900
800
700
600
500
400
300
200
100
0
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)

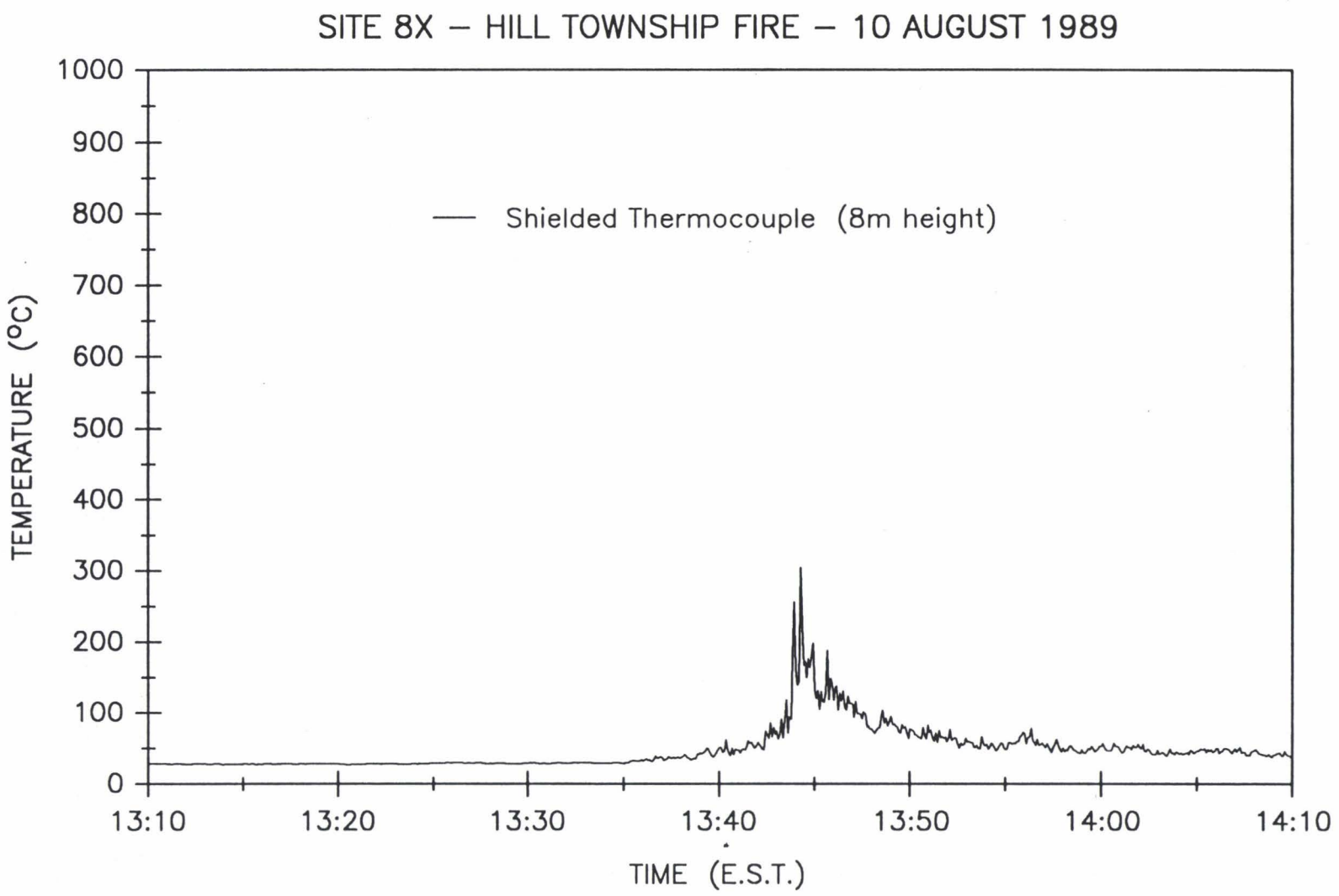

SITE 6X – HILL TOWNSHIP – 10 AUGUST 1989
Unshielded Thermocouple (8m height)
TEMPERATURE (°C)
1000
900
800
700
600
500
400
300
200
100
0
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)

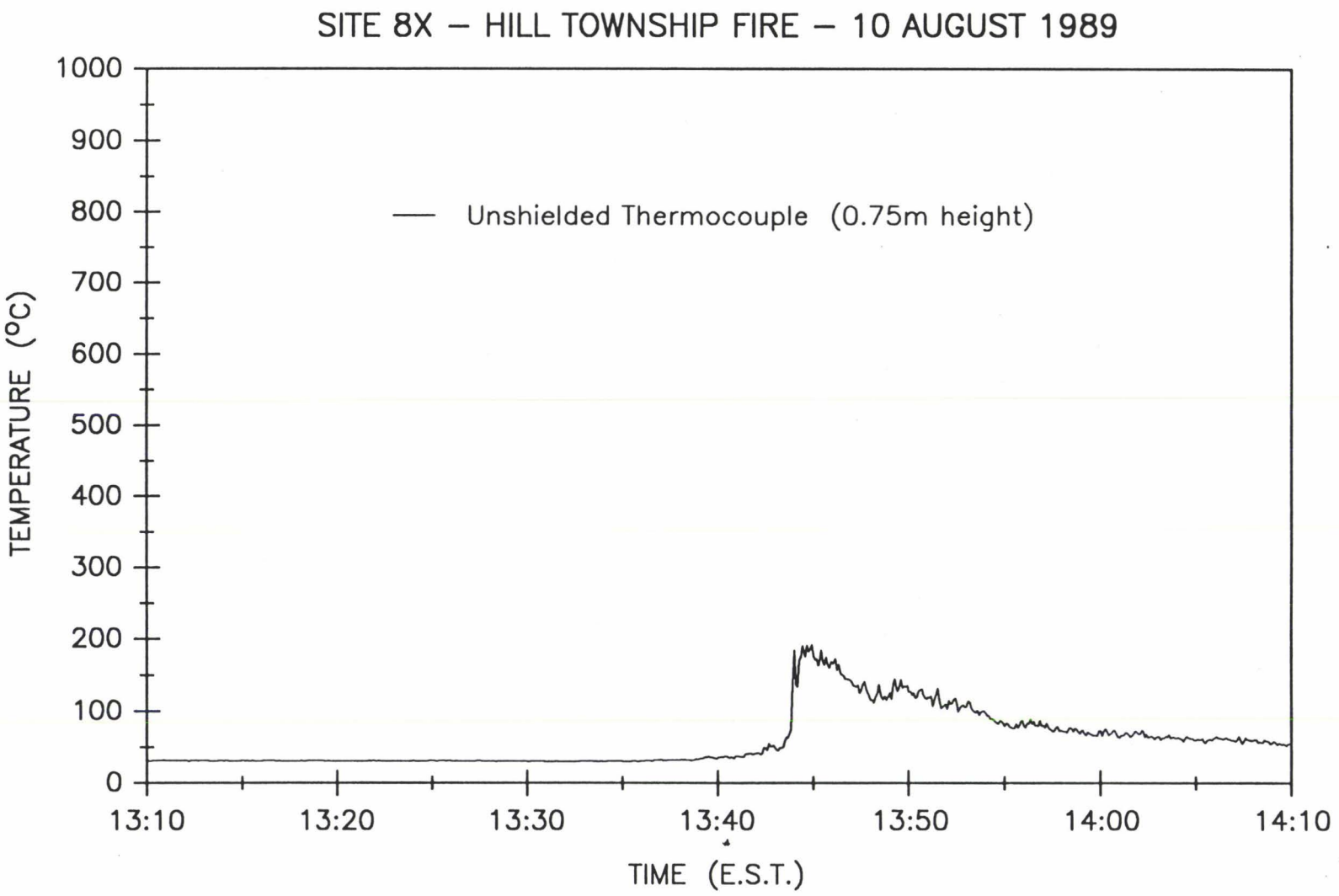

SITE 8X – HILL TOWNSHIP FIRE – 10 AUGUST 1989
Shielded Thermocouple (0.75m height)
TEMPERATURE (°C)
1000
900
800
700
600
500
400
300
200
100
0
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)

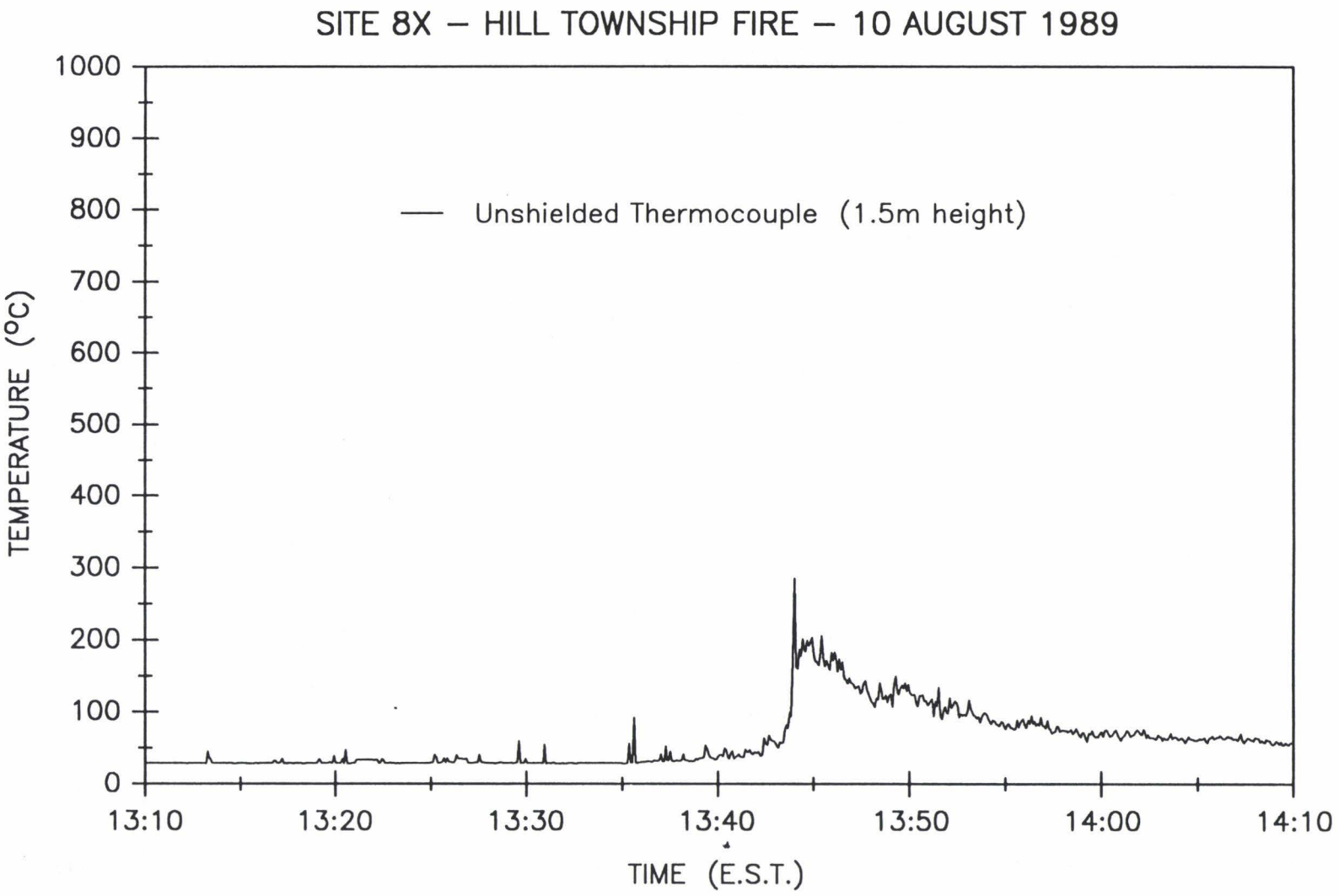

SITE 8X – HILL TOWNSHIP FIRE – 10 AUGUST 1989
Shielded Thermocouple (1.5m height)
TEMPERATURE (°C)
1000
900
800
700
600
500
400
300
200
100
0
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)

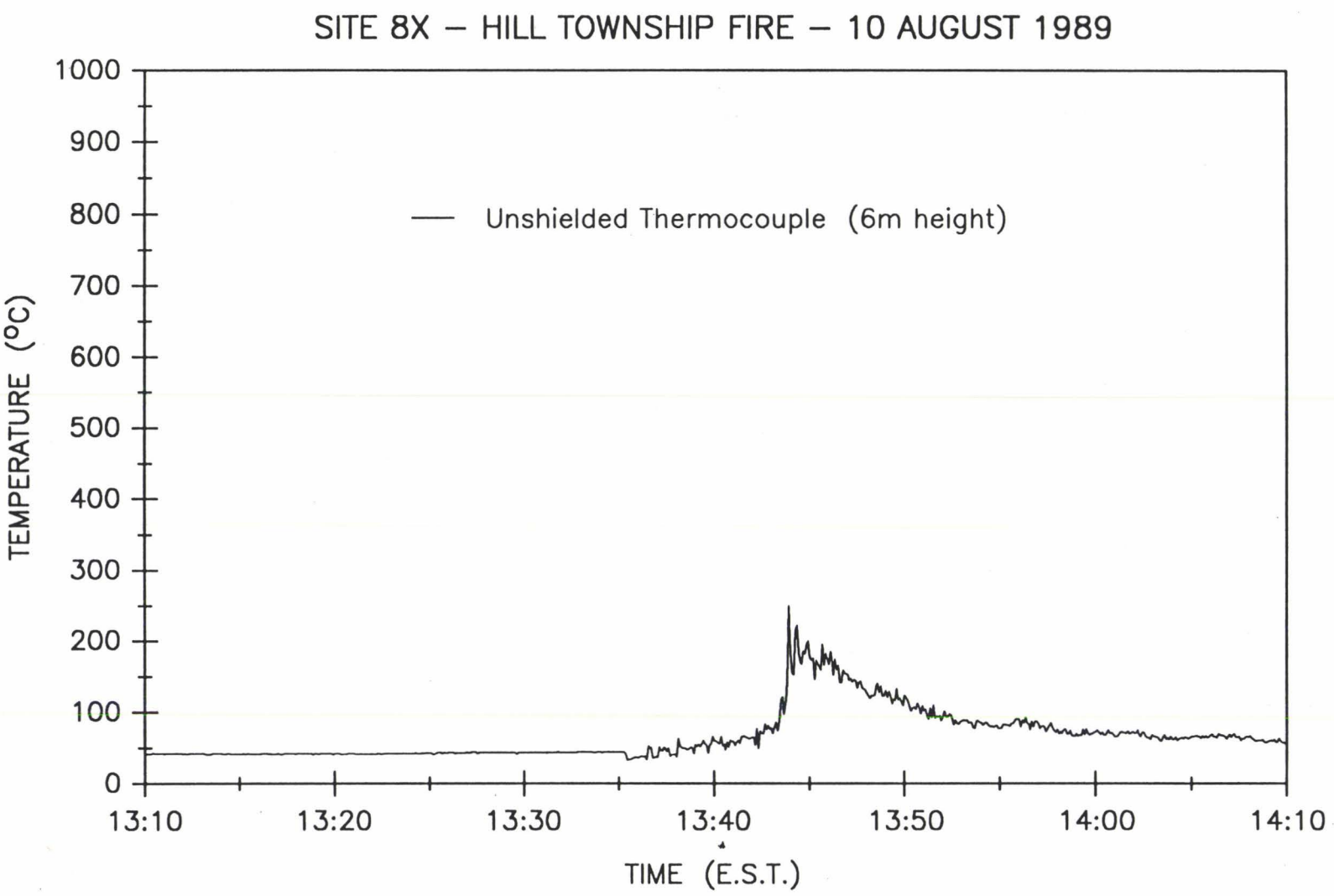

SITE 8X – HILL TOWNSHIP FIRE – 10 AUGUST 1989
Shielded Thermocouple (3m height)
TEMPERATURE (°C)
1000
900
800
700
600
500
400
300
200
100
0
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)

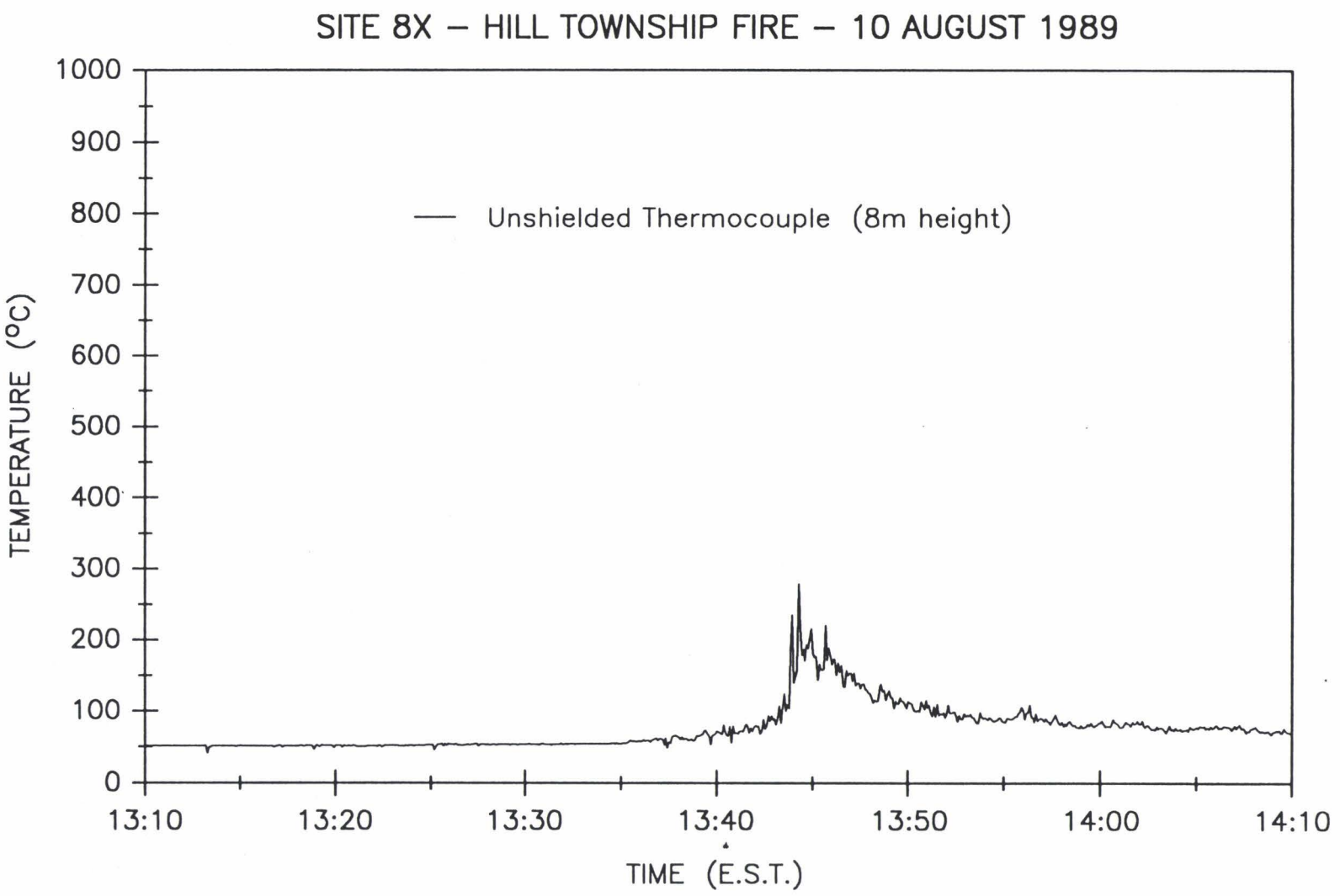

SITE 8X – HILL TOWNSHIP FIRE – 10 AUGUST 1989
Shielded Thermocouple (6m height)
TEMPERATURE (°C)
1000
900
800
700
600
500
400
300
200
100
0
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)

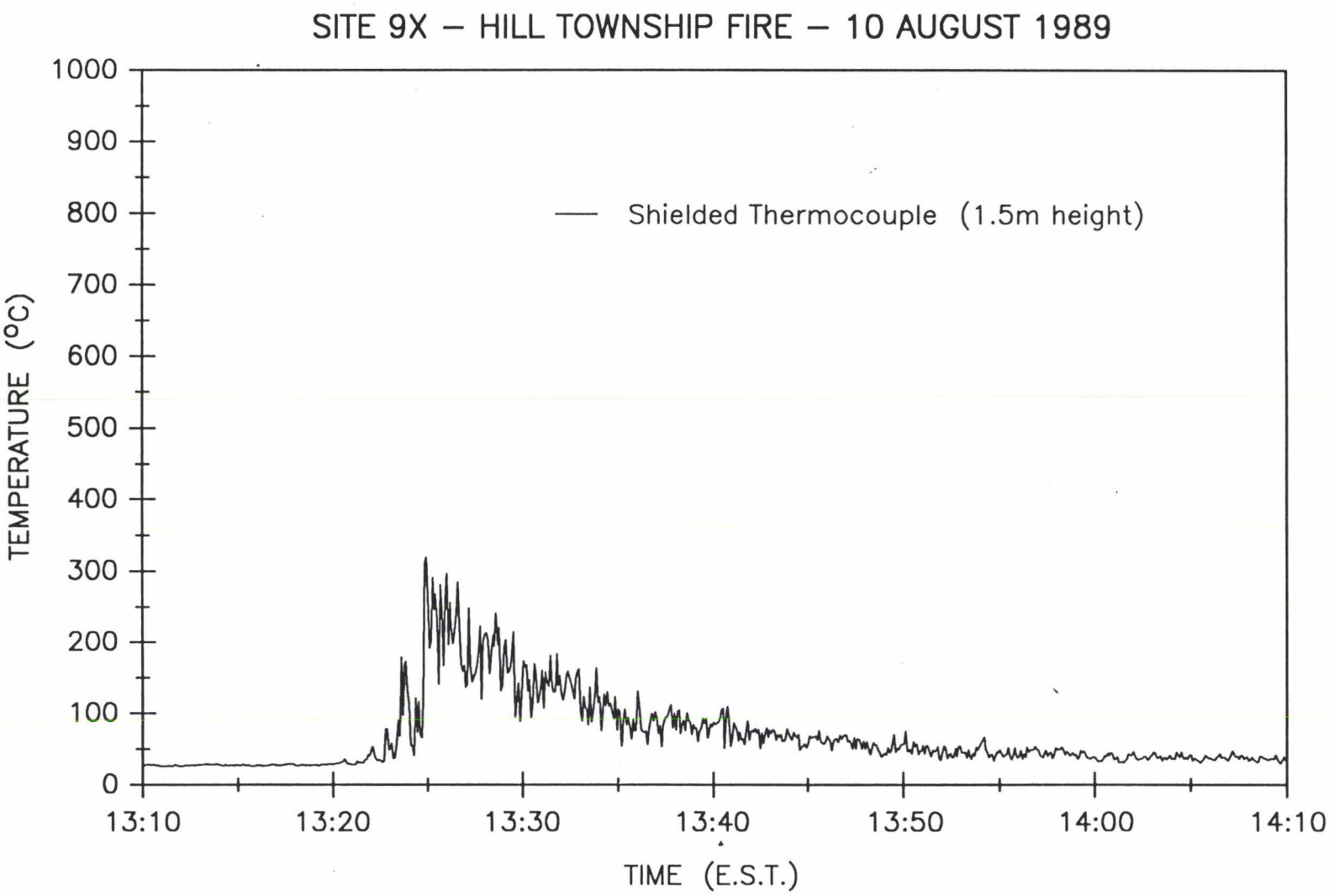

SITE 8X – HILL TOWNSHIP FIRE – 10 AUGUST 1989
Shielded Thermocouple (8m height)
TEMPERATURE (°C)
1000
900
800
700
600
500
400
300
200
100
0
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)

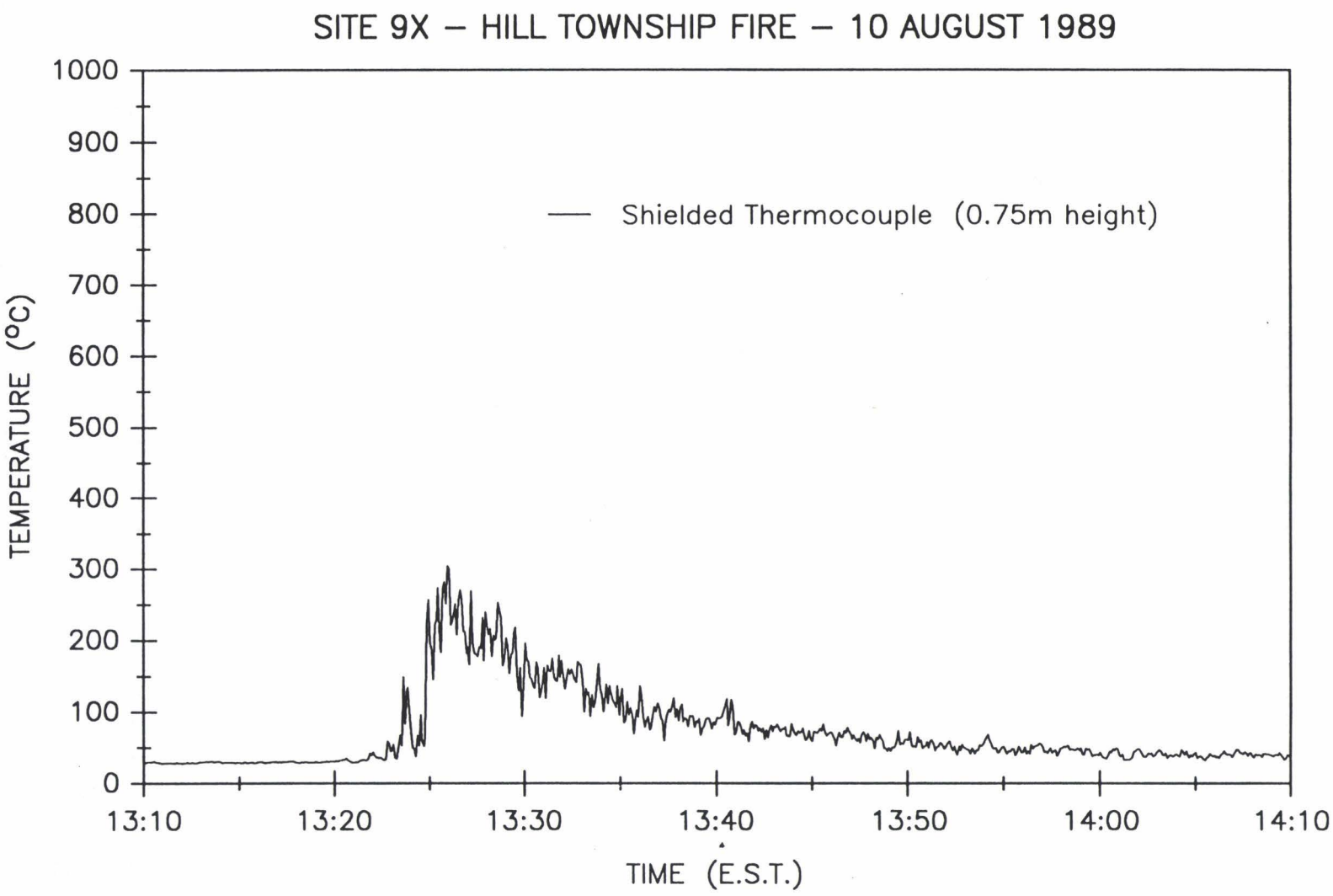

SITE 8X – HILL TOWNSHIP FIRE – 10 AUGUST 1989
Unshielded Thermocouple (0.75m height)
TEMPERATURE (°C)
1000
900
800
700
600
500
400
300
200
100
0
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)

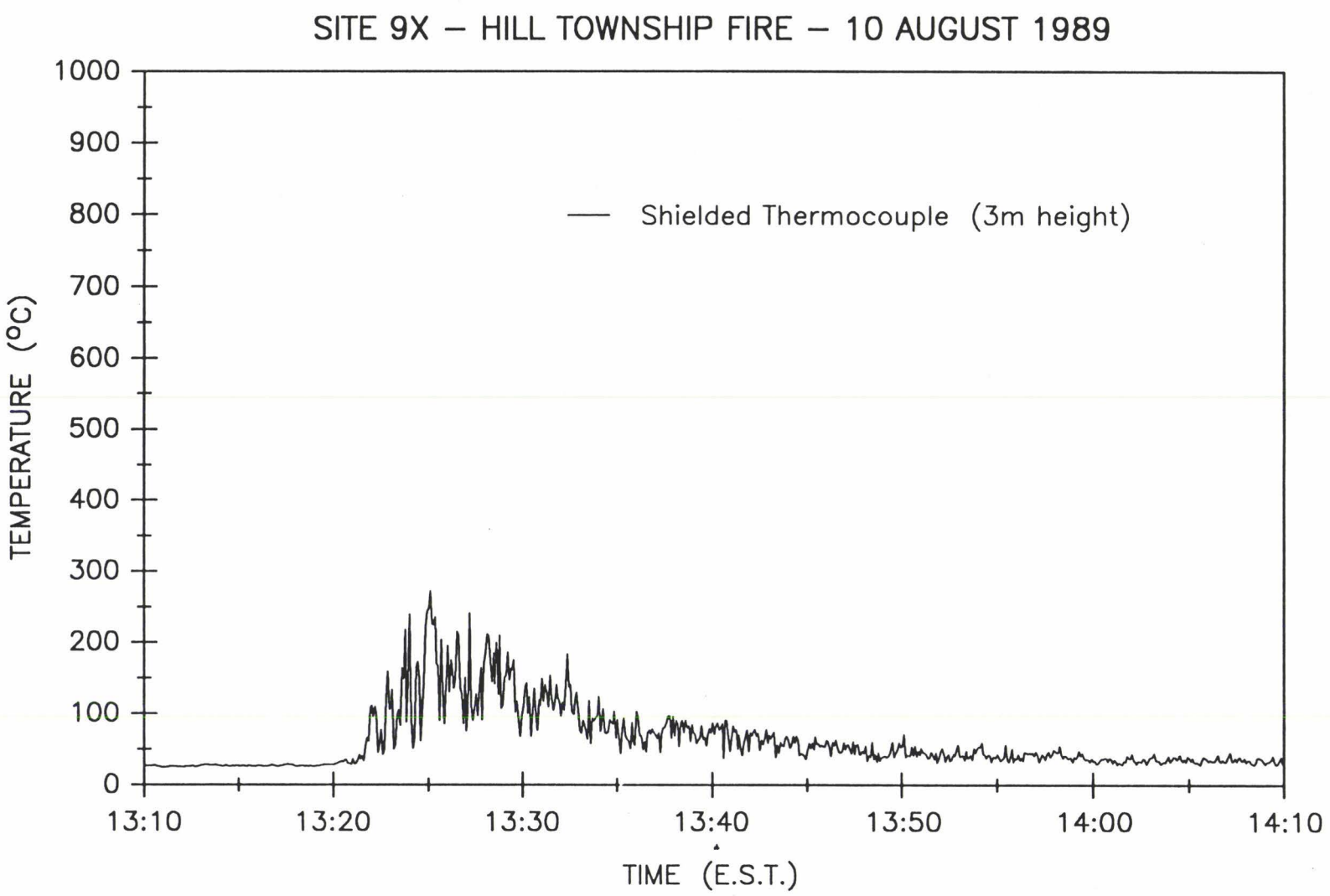

SITE 8X – HILL TOWNSHIP FIRE – 10 AUGUST 1989
Unshielded Thermocouple (1.5m height)
TEMPERATURE (°C)
1000
900
800
700
600
500
400
300
200
100
0
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)


SITE 8X – HILL TOWNSHIP FIRE – 10 AUGUST 1989
Unshielded Thermocouple (6m height)
TEMPERATURE (°C)
1000
900
800
700
600
500
400
300
200
100
0
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)


SITE 8X – HILL TOWNSHIP FIRE – 10 AUGUST 1989
Unshielded Thermocouple (8m height)
TEMPERATURE (°C)
1000
900
800
700
600
500
400
300
200
100
0
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)


SITE 9X – HILL TOWNSHIP FIRE – 10 AUGUST 1989
1000
900
800
700
600
500
400
300
200
100
0
TEMPERATURE (°C)
Shielded Thermocouple (1.5m height)
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)


SITE 9X – HILL TOWNSHIP FIRE – 10 AUGUST 1989
Shielded Thermocouple (0.75m height)
TEMPERATURE (°C)
1000
900
800
700
600
500
400
300
200
100
0
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)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Shielded Thermocouple (3m height)
TEMPERATURE (°C)
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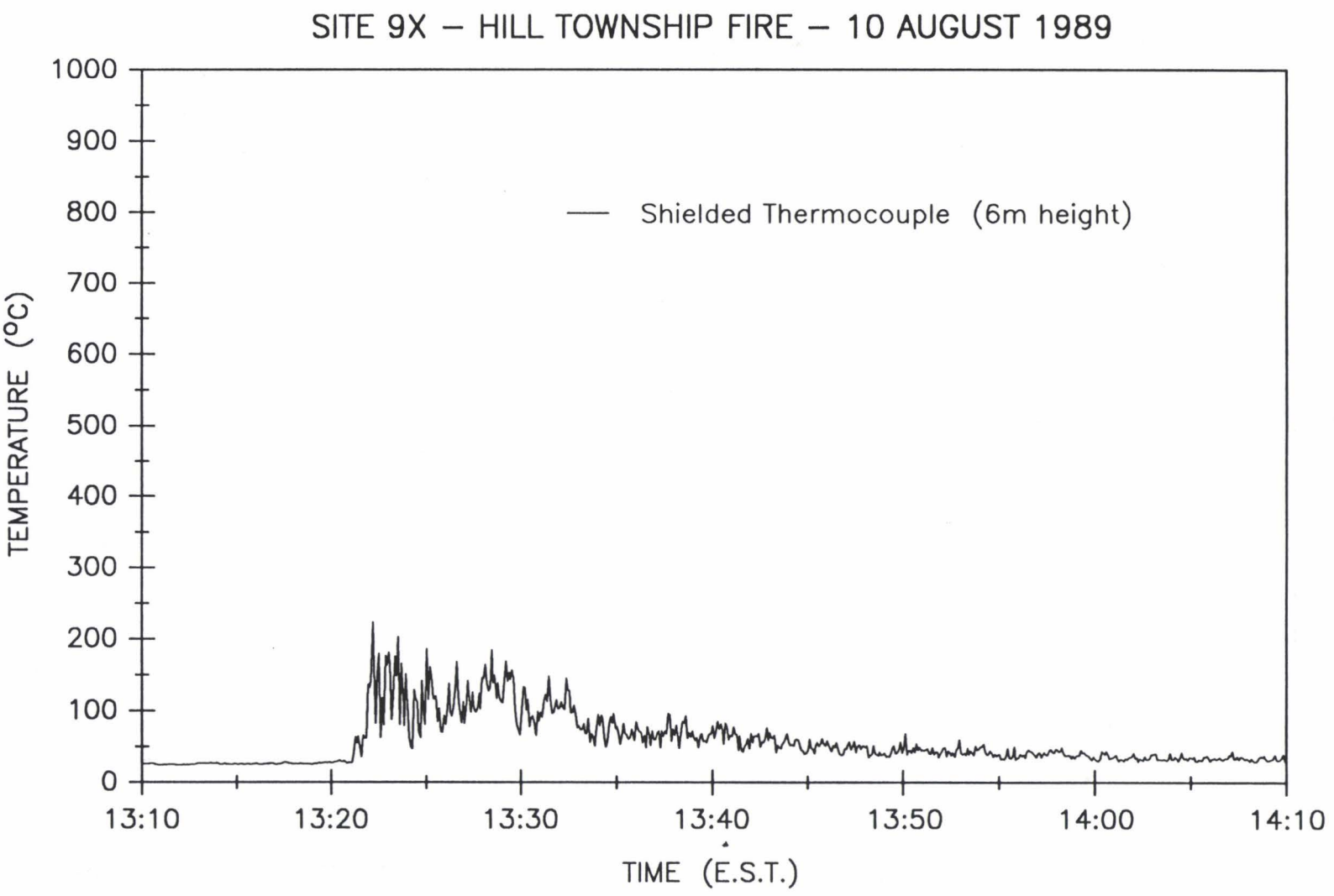
900
800
700
600
500
400
300
200
100
0
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)


SITE 9X – HILL TOWNSHIP FIRE – 10 AUGUST 1989
Shielded Thermocouple (6m height)
TEMPERATURE (°C)
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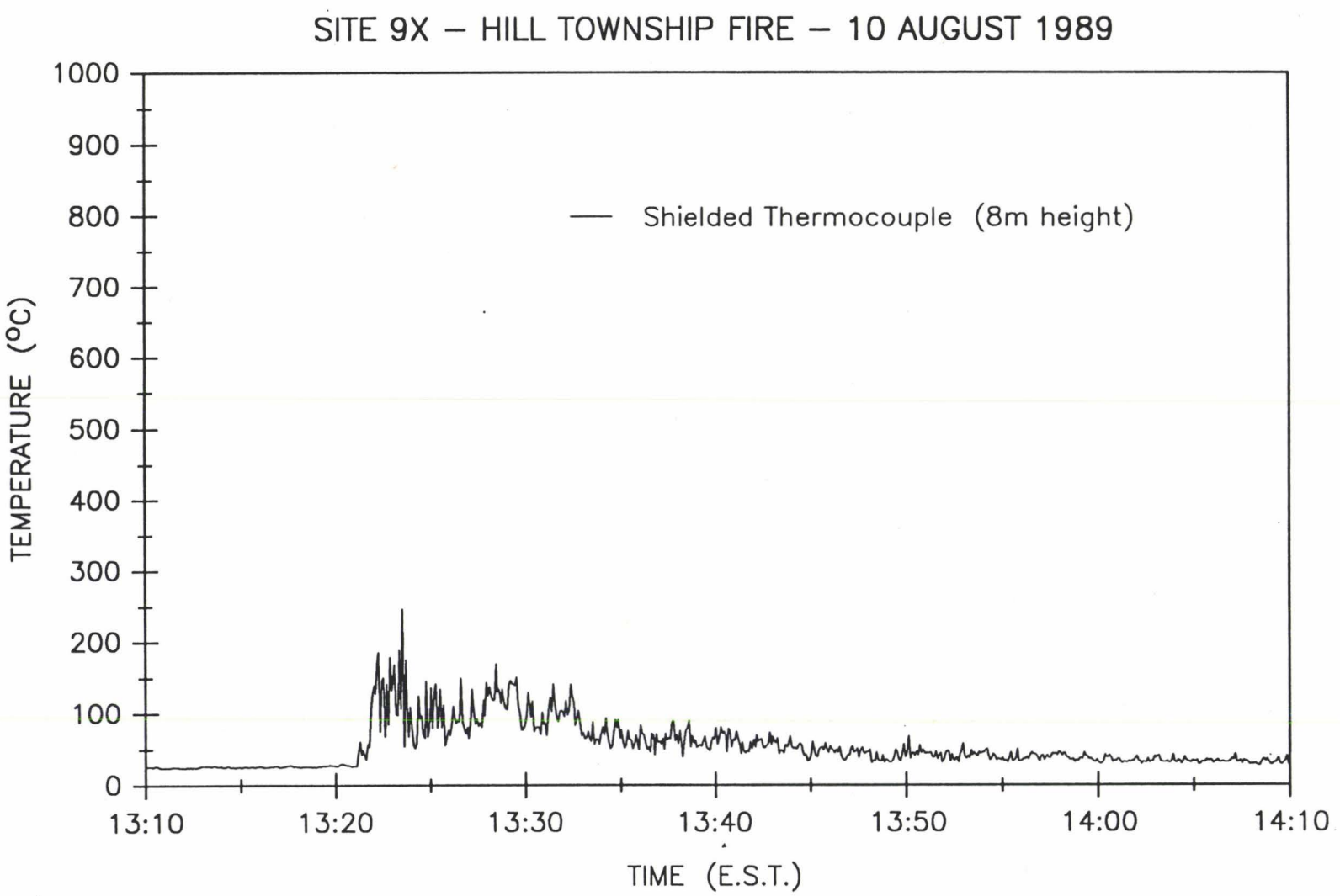
900
800
700
600
500
400
300
200
100
0
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)


SITE 9X – HILL TOWNSHIP FIRE – 10 AUGUST 1989
Shielded Thermocouple (8m height)
TEMPERATURE (°C)
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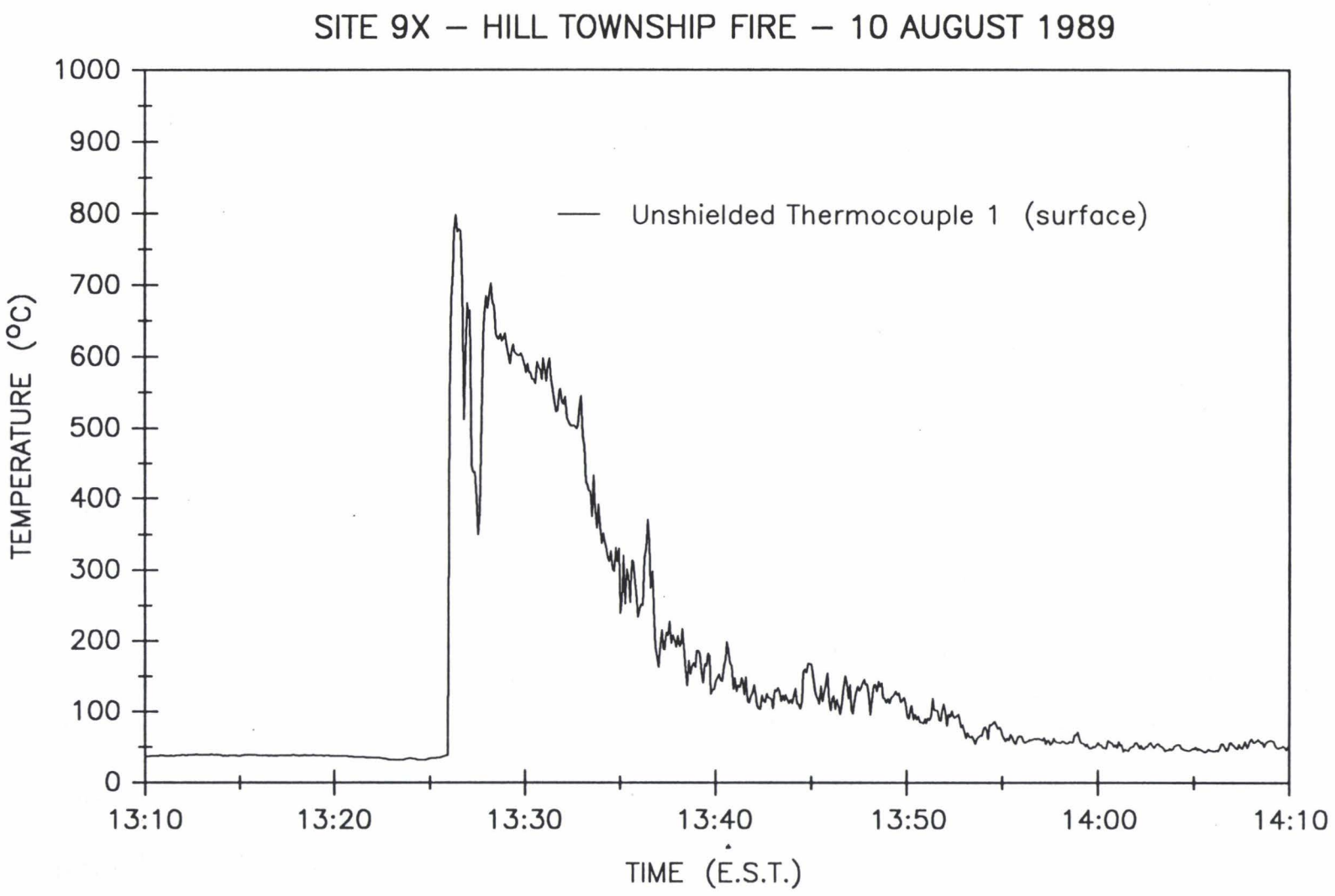
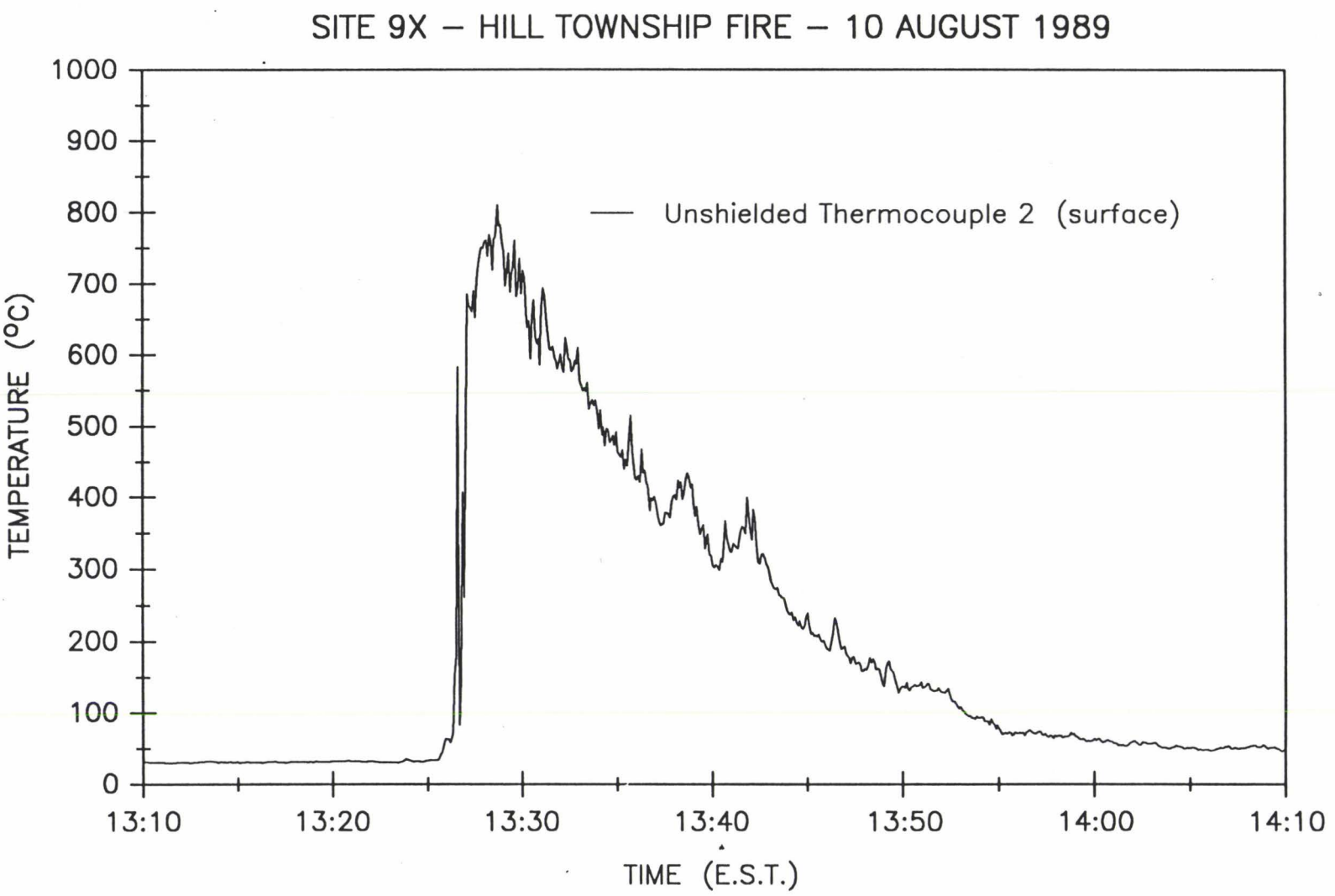
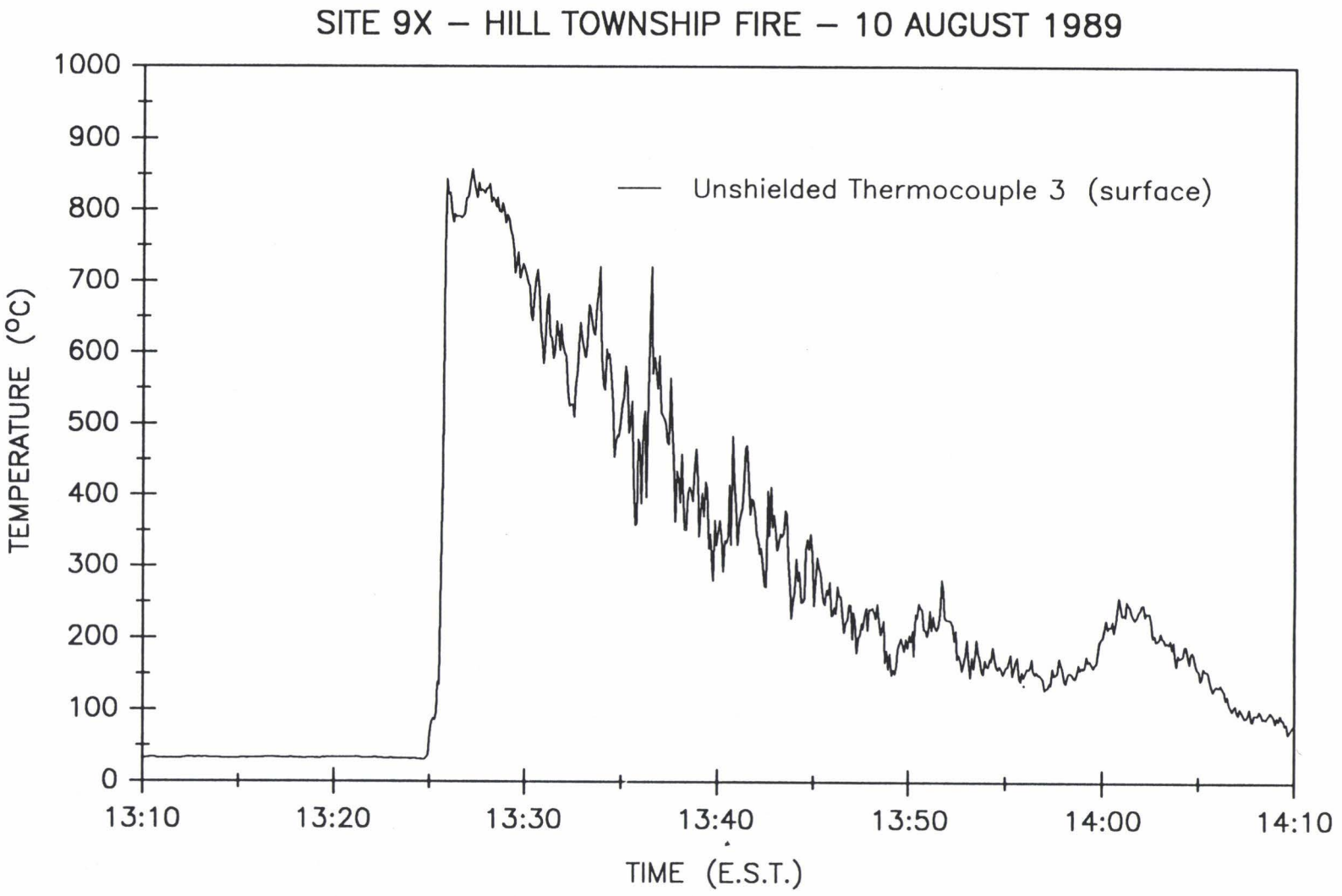
900
800
700
600
500
400
300
200
100
0
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)


SITE 9X – HILL TOWNSHIP FIRE – 10 AUGUST 1989
1000
900
800
700
600
500
400
300
200
100
0
TEMPERATURE (°C)
Unshielded Thermocouple 1 (surface)
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)


SITE 9X – HILL TOWNSHIP FIRE – 10 AUGUST 1989
Unshielded Thermocouple 2 (surface)
TEMPERATURE (°C)
1000
900
800
700
600
500
400
300
200
100
0
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)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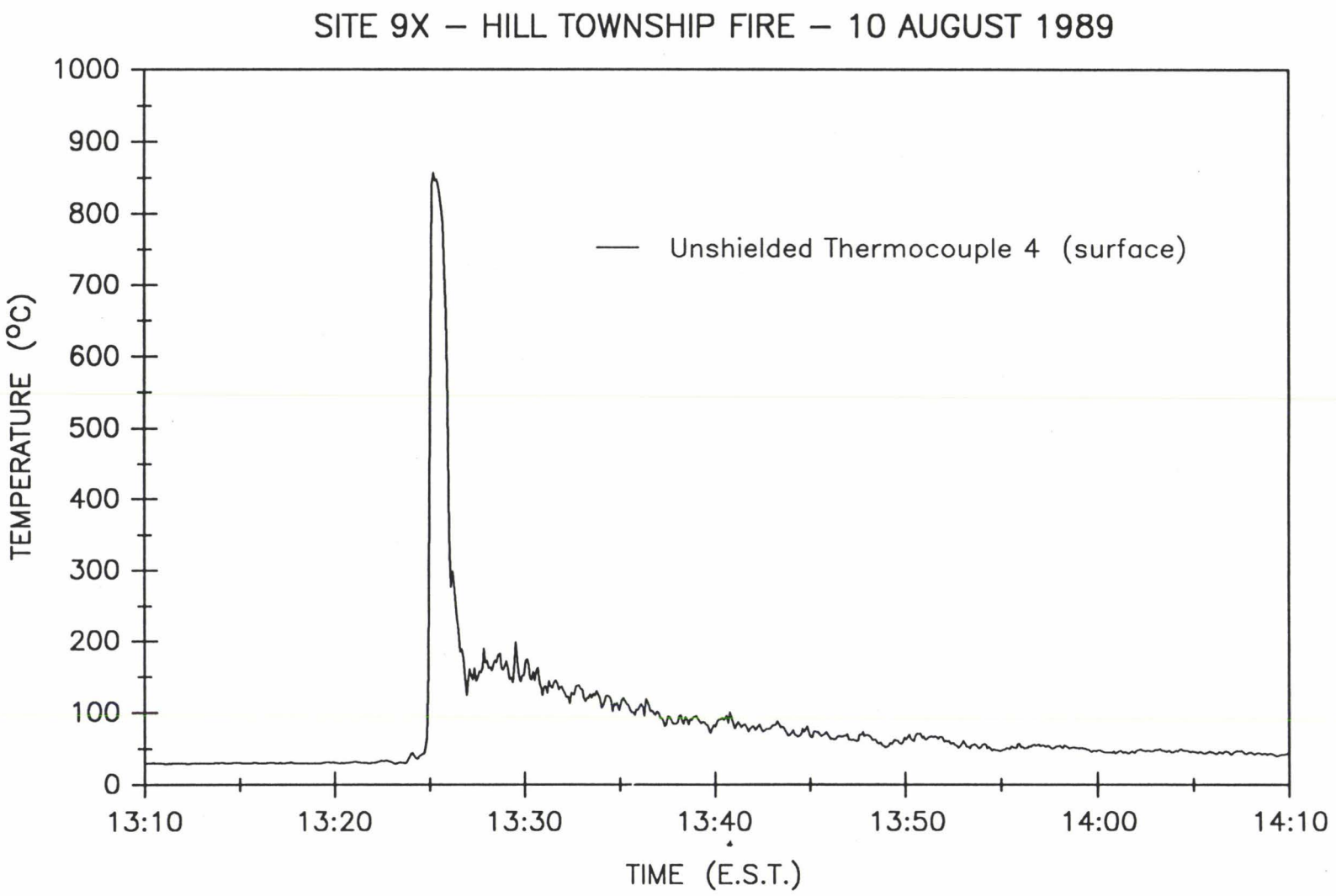
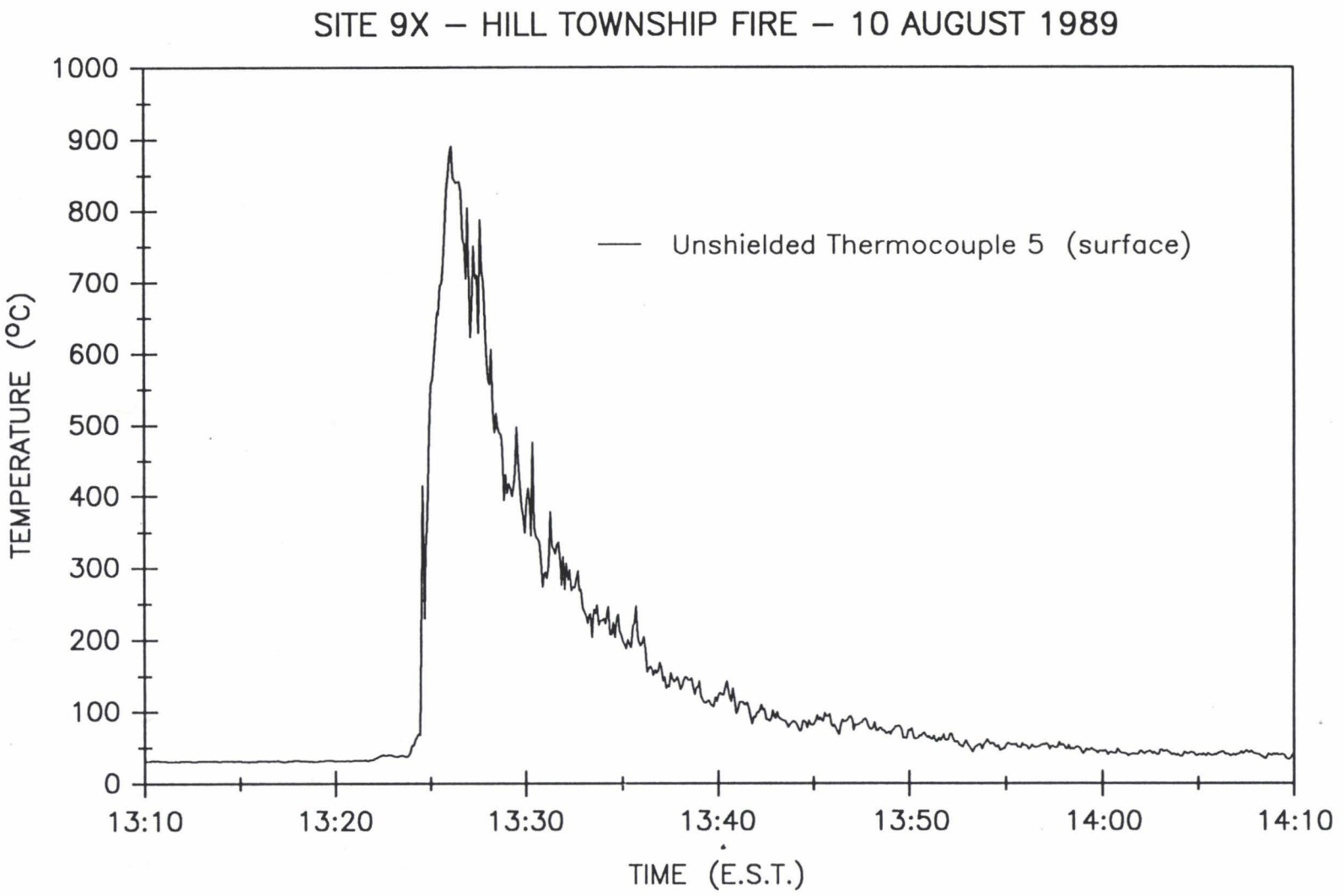
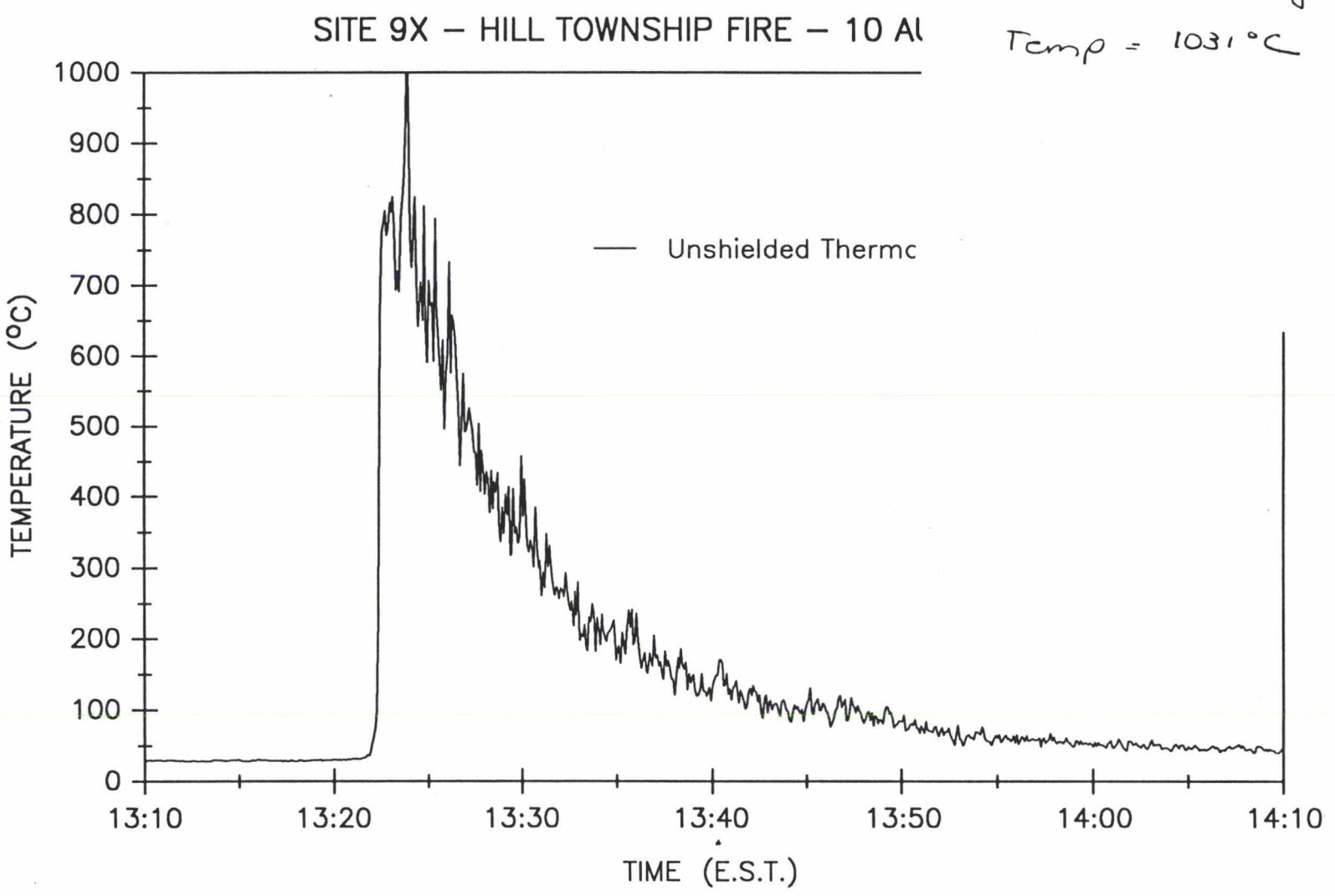
Unshielded Thermocouple 3 (surface)
TEMPERATURE (°C)
1000
900
800
700
600
500
400
300
200
100
0
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)

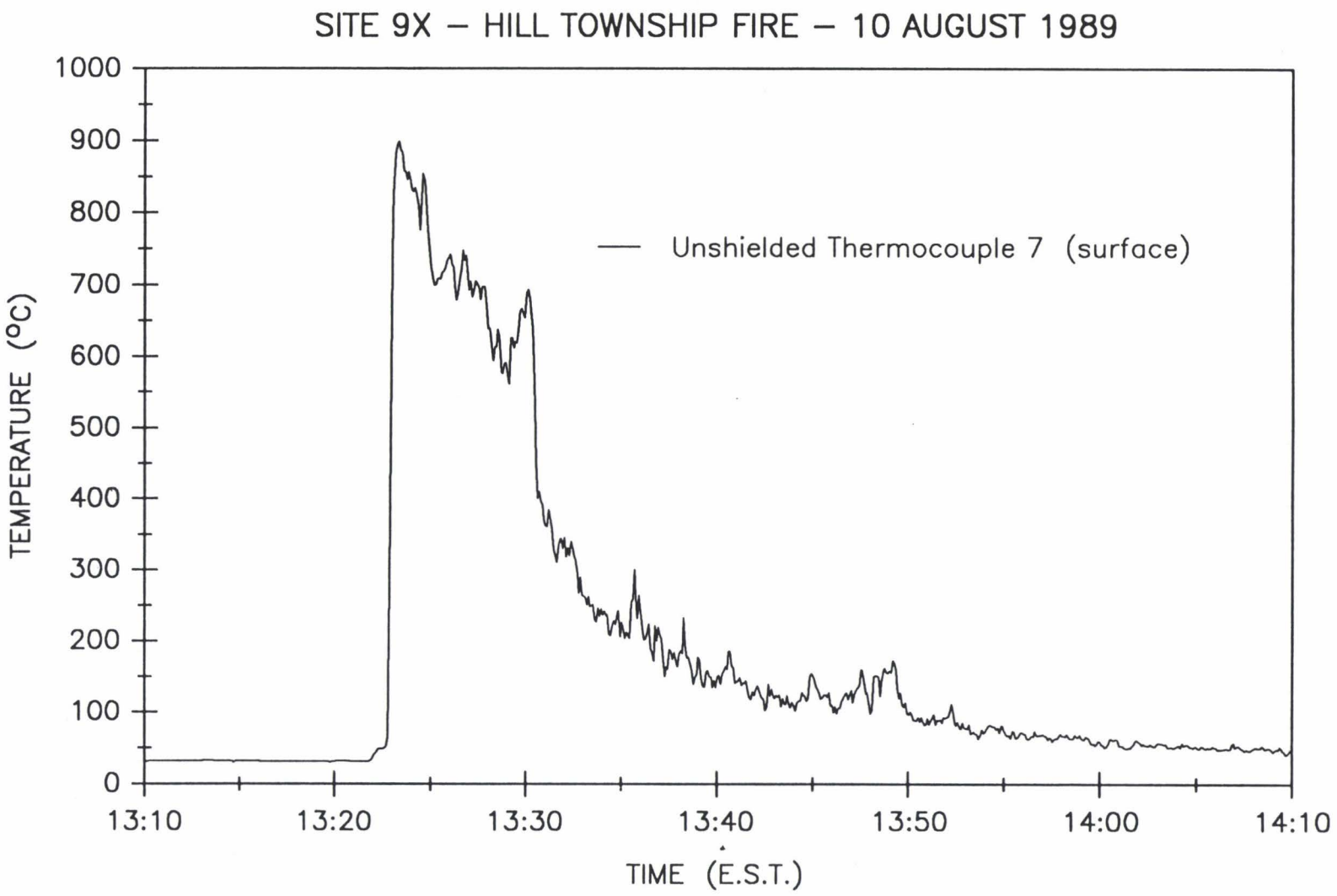

SITE 9X – HILL TOWNSHIP FIRE – 10 AUGUST 1989
1000
900
800
700
600
500
400
300
200
100
0
TEMPERATURE (°C)
Unshielded Thermocouple 4 (surface)
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)

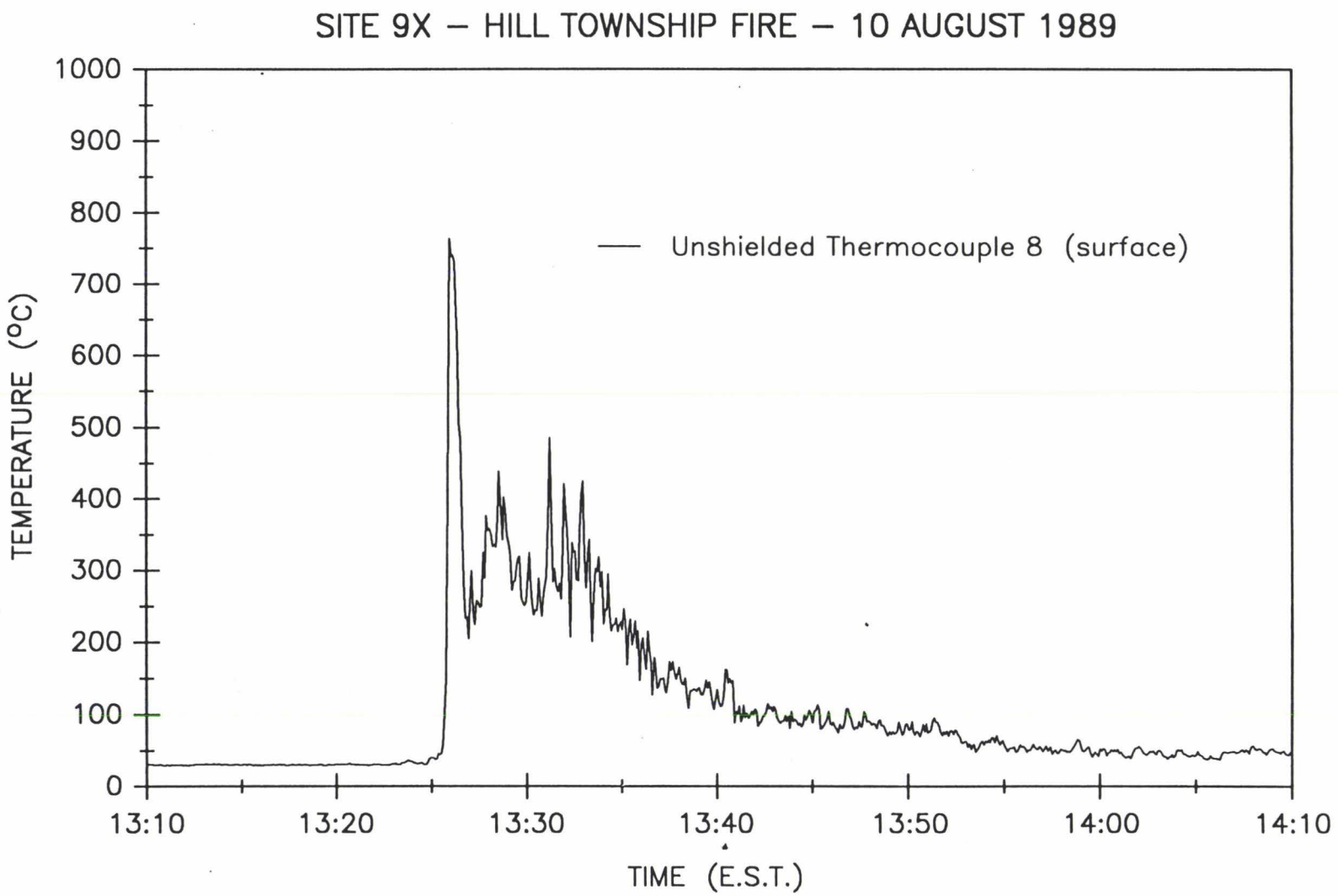

SITE 9X – HILL TOWNSHIP FIRE – 10 AUGUST 1989
TEMPERATURE (°C)
1000
900
800
700
600
500
400
300
200
100
0
Unshielded Thermocouple 5 (surface)
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)

graph goes out of range

Temp = 1031°C




SITE 9X – HILL TOWNSHIP FIRE – 10 AUGUST 1989
TEMPERATURE (°C)
1000
900
800
700
600
500
400
300
200
100
0
Unshielded Thermocouple 7 (surface)
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)


SITE 9X – HILL TOWNSHIP FIRE – 10 AUGUST 1989
Unshielded Thermocouple 8 (surface)
TEMPERATURE (°C)
1000
900
800
700
600
500
400
300
200
100
0
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)

GOAL 6 (OBJECTIVE J)

TO EVALUATE THE PERFORMANCE OF VARIOUS SENSOR DESIGNS.

PROGRESS TO DATE:

Several sensor designs and configurations were tested and evaluated. Effective evaluations of several systems was not possible. The Palmer anemometer did not reach me in the field until after the date of the burn. The SAIC line path averaging system failed early on in the fire and so could not be effectively evaluated. The evaluation of other systems was carried out as planned, including wind tunnel testing of the thermal anemometers. The results of the evaluation are provided in the following pages and will be incorporated in the final report.

BACKGROUND INFORMATION

IOWA'S contribution to the overall project was divided into three distinct aspects. (I) IOWA,in conjunction with PSRC, was to deploy 1 fire spread and 3 turbulence arrays following a PSRC design. (II) In addition to, and separate from, the joint PSRC-IOWA effort to instrument 4 in-fire sites, Iowa independently equipped and deployed fire dynamics towers of it's own design at 5 sites within the fire perimeter and evaluated several types of sensors including the thermal anemometers, the use of shielded thermocouples, circular arrays of thermocouples for measureing fire spread etc. Both of IOWA's roles will be discussed below. (III) A detailed evaluation of the turbulence and spread arrays.

(I) IOWA'S JOINT EFFORT WITH PSRC

As part of the overall research effort IOWA prepared and deployed two of the three turbulence arrays and the spread array designed by PSRC. By agreement the responsibility for the design was PSRC's. The responsibility for preparation, deployment and primary data analysis (data dumping, calibration, data quality assurance, etc.) for two of the turbulence arrays and the spread array was IOWA'S. PSRC was to carry out the actual turbulence analysis using the data and was itself responsible for deployment of one turbulence array.

The basis for research, objectives, a schematic of equipment, data analysis procedures to be used, and suggested applications for results of research for all three turbulence arrays and the one spread array designed by PSRC have been described in Appendix D (of the overall study plan) and need not be repeated here. The following discussion provides further information on: the equipment location; methods used; and in particular the limitations of the joint PSRC-IOWA data set.

SCHEMATIC OF LOCATION OF EQUIPMENT

Figure 1 below provides a somewhat more detailed indication of the relative position of the joint PSRC - IOWA tower arrays, spread array and the independently designed and deployed IOWA towers (to be discussed in part B). The two turbulence arrays and the spread array which Iowa deployed following the PSRC design are also distinguished from the one turbulence array which PSRC deployed.

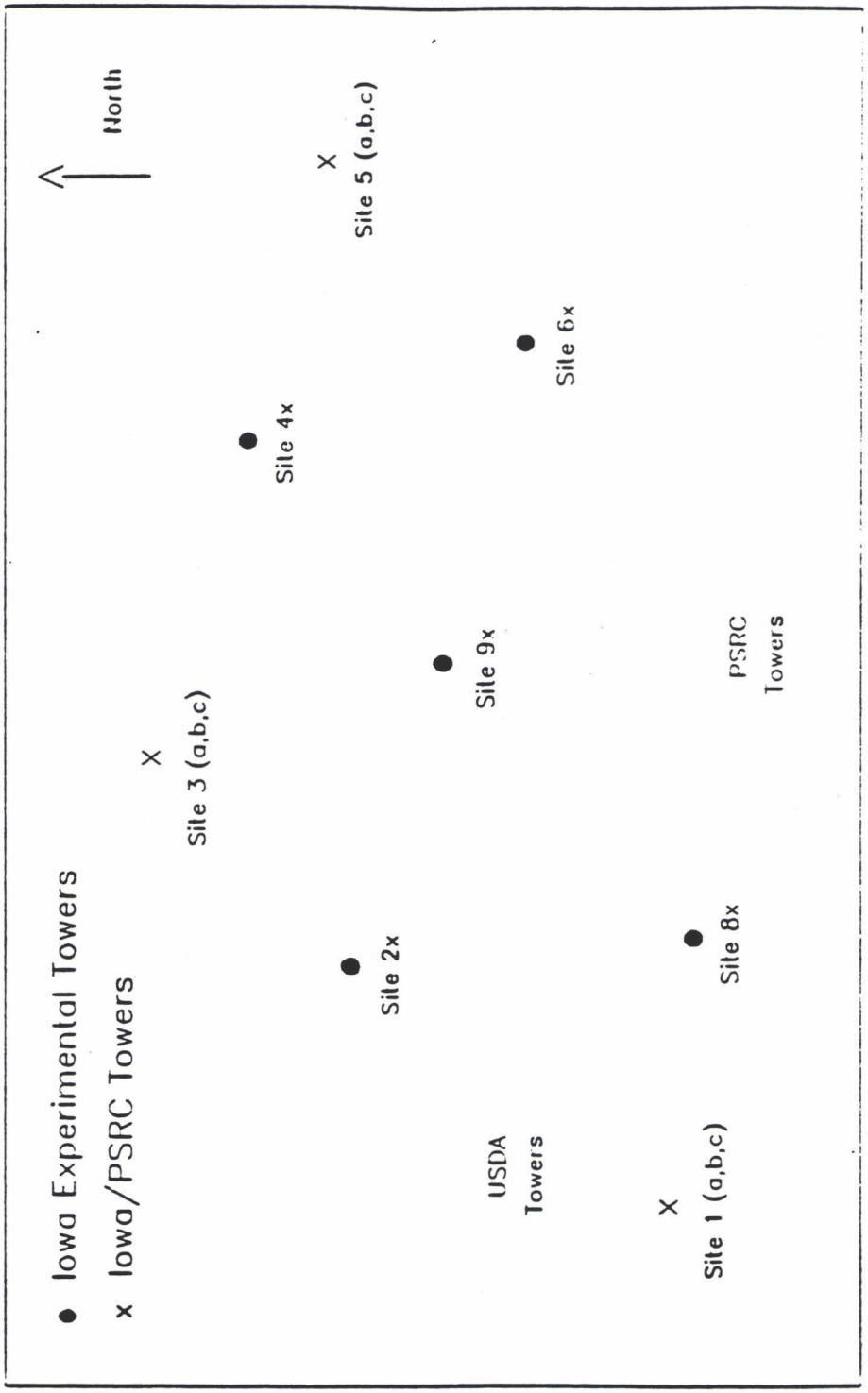


Figure 1. Iowa in-fire instrumentation grid. The IOWA sites are distinguished from the PSRC-IOWA sites and the PSRC and USFS sites.

METHODS

Turbulence Arrays

General aspects of the PSRC designed turbulence arrays are provided in the PSRC experimental design and will not be repeated here. A number of methodological and design decisions should be pointed out. In particular, it should be noted that PSRC, in it's design, specified:

1. thermal anemometers be used to measure the in-fire vertical wind fluxes (specifically Sierra thermal anemometers model 640-99-18"-HTC-C6); PSRC also requested that the thermal anemometers be housed in vertical tube aluminum shields of PSRC's design;
2. the horizontal wind velocity and direction be measured by Qualimetrics model 2032 and 2005 sensor respectively (the 2032 velocity sensor is a two count per revolution pulse counting cup anemometer);
3. the clocks operating each of the data loggers be manually synchronized;
4. the sampling rate in the turbulence arrays be every two seconds;
5. the temperature sensors be twisted, soldered, type K, 24 gauge thermocouples; and that the temperature sensors be mounted in 2" vertical aluminum tube shields of PSRC design;
6. the spacing on one of the arrays prepared and deployed by IOWA be 10 m and on the second IOWA array that the spacing be 20 m ;

It was also requested that the third turbulence array, with a 10 m spacing, be prepared and deployed by PSRC.

With respect to the above design requirements and before equipment orders were placed and the finalization of the plans occurred IOWA made a number of recommendations:

1. that shielded thermal anemometers not be the sensors of choice for the vertical flux measurements;
2. that generating anemometers be used instead of pulse counters for the horizontal velocity measurements;
3. that the data logger clocks be electronically synchronized;
4. that a sampling rate faster than every 2 seconds would be desirable;
5. that the temperature sensors be low angle, butt welded, thermocouples not twisted, soldered thermocouples; and that the shielding of the thermocouples be reconsidered;
6. that the spacing between arrays, given available resources, not be varied;

All of the above recommendations were rejected by PSRC. They requested that the original design be followed. This was done with one exception - IOWA insisted on the use of welded thermocouples in the towers it deployed. PSRC, in the one array they deployed, used twisted, soldered thermocouples. PSRC's position was that this should have no significant impact on the data.

Spread Array

The PSRC designed spread array was also be prepared and deployed by IOWA using the same sensors and sensor placement strategy as on each of the turbulence array towers except that the spread array towers will be placed three in a line and additional ground temperature sensors will be deployed. The actual layout of the spread array is shown in the PSRC experimental design. The PSRC design, as originally proposed, involved the use of 5 dataloggers with a maximum differential thermocouple capacity of 8 temperature sensors (effectively only 6 per logger because of other sensor inputs). Thus 30 thermocouples could have theoretically been deployed under the original PSRC plan. This design goal of PSRC was essentially met. The final design settled upon at the time the operational research plan was locked in involved the use of three wind and temperature sensing towers and a series of ground located thermocouples with Iowa contributing additional supplemental equipment to enable the number of thermocouples required in the PSRC design (30) to be provided.

While the desirability of more ground thermocouples in the spread array is obvious the limitations inherent in the PSRC design (specifically channel capacity limitations for the data loggers they specified for the spread array) precluded the deployment of more thermocouples at this time. (A much larger number of additional thermocouples could be deployed, for example, if the design were altered somewhat and different recording systems used. This possibility was presented to PSRC and discussed with PSRC and it's desirability agreed to by all. Unfortunately, this much larger capacity was not part of the initial design specified by PSRC or the research plan at the time the plan, for operational purposes, was locked in.

LIMITATIONS OF THE DATA SET

PSRC specified the turbulence array design, the equipment and the deployment pattern. Iowa, after making a number of recommendations which were declined, prepared and deployed the turbulence and spread array equipment in accordance with the PSRC requests (with one exception - IOWA will use welded thermocouples while PSRC will use soldered, twisted thermocouples on the array it is deploying).

Of particular concern here are the following data constraints associated with the present design, deployment and data.

1. The use of shielded thermal anemometers.

PSRC requested the use of Sierra thermal anemometers operated within a vertical aluminum shield to measure the vertical wind fluxes. While the use of thermal anemometers in more conventional environments is well established, the use of a thermal anemometer in a dynamic fire environment poses serious difficulties. The most significant problem involves the inability of the anemometer to effectively compensate for rapid changes in temperature in a fire. The thermal anemometers specified and used are inherently incapable of compensating for the rapid temperature changes taking place in the flaming front of the fire and to a lesser degree even the smoldering phase. While the time constant for differing thermal anemometers will vary, the time constant for thermal compensation for the Sierra thermal anemometers which PSRC specified, as stated by the manufacturer, is no better than 15 seconds while the actual velocity head which senses the velocity is much faster (on the order of 1 second). The net result, under rapidly changes air temperature conditions is that the temperature compensation is not able to keep up with or correct the velocity readings. The errors resulting moreover, are not minor. In many cases the compensation errors resulting from this problem may be so large that the thermal velocity sensors will read 0 m/s velocity or near 0 m/s during the flaming front arrival, precisely when higher velocities were expected and in fact occur. The problem will persist in the smoldering phase with little capacity to correct the errors leaving one with limited confidence in the measurements being made.

The issue is further compounded by the effects of the shields designed by PSRC to enable the thermal anemometers to be used as vertical velocity flux sensors. It may be expected that the presence of the shield will itself generate flow turbulence and create a very erroneous vertical flux reading. This problem is likely to be particularly acute under near horizontal flows and in general at higher wind velocities. Based upon past experience with in-fire winds IOWA has previously measured, this problem is likely to become particularly acute with horizontal winds exceeding 10 m/s.

The combined effect of the massive temperature compensation errors and the problems caused by the aluminum shields is that the data is likely to be confusing, contradictory and of limited reliability.

Finally, the problems associated with the thermal anemometers are further compounded by the inherent inability of the thermal anemometers to indicate whether the flow direction is up or down. Without knowledge of the vertical flux direction as well as the vertical flux magnitude it becomes very difficult to determine the heat or energy flux pattern.

2. The use of pulse counting anemometers to measure the horizontal winds.

The use of pulse counting cup anemometers is a well established and standard technique in meteorology and hydrometeorology. The use of a variety of designs of pulse counting cup designs in fire has also been a common practice (a number of designs such as the Palmer type and other have been used over the years). The difficulty which arises with the use of pulse counters in this application centers on the specific application itself. The pulse counters specified by PSRC operate on a 2 count per revolution basis and in this application were scanned every 2 seconds. The combination of the pulse signal and the scan rate means that these units will be operating in the fire as horizontal wind averaging systems. They will totalize the counts over a two second period and then the average velocity over that period will be calculated. When combined with the horizontal direction sensors (operated in parallel with them) these cup units should provide a good general indication of the broader fluxes in the horizontal wind field.

However, when deployed in a turbulence array as was the case here, problems arise. The response time of these units is not particularly fast for turbulence work and their use in an averaging mode which is so slow will present difficulties. The fire environment is an extremely dynamic one in which rapid wind shifts and fluxes are common. Based on previous in-fire measurements made by IOWA it would not be uncommon, for example, for a gust to sweep past a point such that a horizontal wind of 10 m/s would increase to 20 m/s in a 2 second period. Assuming, for example, a gust hits the array half way between scans and an instantaneous response time (obviously not the case) the cup would register this as an increase from 10 to 15 m/s for this period. It would miss the peak value of 20 m/s and also only be able to determine the arrival of the wind gust itself to within a 2 second time frame.

With the towers in each array only 10 and in one case only 20 meters apart this means the arrival of a gust at each tower is only approximate within a 2 second window. For eddy correlation analysis on a three point tower array with winds in the 10 - 30 m/s range this will present serious problems. Turbulence and the associated correlation analysis over short distances generally requires much higher accuracy in terms of when fluxes occur and the magnitude of those fluxes. Turbulence analysis with relatively long time base averaged wind data in such a situation will be difficult.

3. The manual synchronization of the data logger clocks.

As per PSRC's request manual synchronization of the clocks between the data loggers in the turbulence arrays was carried out. Such manual synchronization will result in time bases which were generally within 0.5 seconds of one another. A 0.5 second error is, in and of itself not a major concern, if one is comparing data from towers spaced at some distance from one another (on the order of a hundred or several hundred meters) and when dealing with winds on the order of 10 -30 or even 40

m/s.

Unfortunately such a variability is likely to be quite significant for measurements taken when comparison of data from towers only 10 or 20 meters apart is being made. If a gust of wind strikes one tower at 0.0 seconds and strikes a different tower in the array 0.75, 1.0, or 1.5 seconds later the impact on the correlation and turbulence analysis is to say the least significant. The fact that the readings (as indicated above) are 2 second average values further complicates the matter. Determining turbulent transfers under such a combination of variabilities between time bases and only relatively broad, wide band, average velocity data on a such a spatial (10 m or 20 m) will be difficult given the large number of uncertainties. Even if some type of rough determination of turbulent activity can be extracted the credibility of the results will be limited.

4. The sampling rate of every two seconds.

The selection of the two second sampling rate by PSRC for the turbulence and spread arrays, while acceptable for the general wind conditions in the fire, poses major problems for the arrays. Most turbulence studies and eddy correlation studies on such a basically micrometeorological scale, require sampling rates at least an order of magnitude or even two orders of magnitude higher speed (0.2 down to 0.02 or 0.01 seconds between scans between scans) in order to enable the correlations to be effective. A 20 m/s gust would only take 0.5 seconds to sweep through an entire PSRC turbulence array and would likely register essentially simultaneously on all three towers. Recall as well that the readings are only 2 second average values not instantaneous values taken at 2 seconds. The ability to separate out the gusts penetration and passage through an array would require much faster readings. Conventional measurement practice would suggest a scan rate at least an order of magnitude and preferably 2 orders of magnitude faster than the flux rate of the phenomenon (in this case the turbulent fluxes).

Finally, the fact that the time bases were not electronically synchronized, but only manually coordinated for the data loggers at each tower means that the readings were not take at the same time. Any effort to compare the results between the towers must also come to terms with this limitation.

5. The placing of the temperature sensors within vertical aluminum shields.

PSRC, in an effort to minimize the effect of radiative heating of the thermocouples, required the thermocouples to be placed inside a vertically mounted 2 inch diameter aluminum shield. The aluminum shields are of PSRC's design and specification. In the case of the three towers (making up one array which they instrumented themselves) PSRC chose to use soldered, large diameter, twisted, thermocouples. In the case of the remaining arrays and all of the other towers which IOWA instrumented

small bead, low angle butt welded thermocouples were employed. In the case of all of the arrays, at PSRC's insistence, the shields were used. While some capacity to correct for the shield effect does exist it will likely require a fairly wide error band being placed around much of the array temperature data. Comparison with temperature data will have to be undertaken with considerable caution.

6. The non-uniform horizontal spacing of the turbulence arrays.

Two of the arrays (the one deployed by PSRC and one of the arrays deployed by IOWA) were to be spaced at 10 m while a third array, deployed by IOWA was at 20 m spacing.

Comparing the results between the different arrays (ie. to study eddy size effects and select an optimal array spacing) will be challenging under the best of circumstance since each array was located at quite different positions in the fire and in different topographic settings and the significance of location and topography would have to be taken into account. There are simply too many difficulties with the data. Any effect of varying the horizontal spacing will likely be lost in all of the other uncertainties associated with this array data. In fact, this variability in the spacing introduces one more uncertainty into the turbulence array data sets - a further complication.

(II) IOWA'S EXPERIMENTAL EFFORTS

BASIS FOR RESEARCH

In addition to the joint PSRC-IOWA study IOWA carried out, independent of PSRC, it's own experimental effort. This effort was intended to contribute to the overall program outlined in the plan of work by contributing in the areas of fire dynamics, equipment development, and the provision of needed inputs to plume dynamics modelling efforts. The specifics of IOWA's study are discussed below. The third area, that of sensor and technology evaluation, is discussed in more detail on the following pages.

Three general objectives of IOWA's efforts were the following:

1. Whole fire objectives

(a) To characterize the overall (whole fire), near surface (10 m), horizontal wind field of the fire utilizing cup anemometers and direction sensors;

(b) To characterize the near surface vertical winds and aspects of the 3-D flow field in the fire using u-v-w (triaxial) anemometers;

(c) To integrate the in-fire near surface (10 m) winds with perimeter wind data using data being collected as part of the overall effort by the Canadian Forest Service;

2. Site specific objectives

(a) To obtain and analyze integrated vertical profile temperature data collected on the towers;

(b) To obtain and analyze localized fire spread rate data for a 20 m diameter, 8 point, ground surface thermocouple arrays deployed within the fire in junction with the towers;

3. Sensor evaluation

(a) To evaluate the in-field performance of various sensor designs.

SCHEMATIC OF LOCATION OF EQUIPMENT

The location of IOWA's own instrumentation systems is indicated in Figure 1. It should be noted that 5 systems will be deployed along with the 3 PSRC designed arrays which IOWA will deploy and the 1 array which PSRC will themselves deploy in such a way as to provide a spatial field of sensors. When combined with data from the USFS array and the Canadian perimeter towers the resulting sensor field should provide an adequate data set to enable the above goals to be met.

SCHEMATIC OF EQUIPMENT ON TOWERS/GROUND/ETC.

The equipment which was placed on the IOWA designed and equipped towers are shown in Figure 2 and are listed below.

- a cup anemometer (identical to the metal cup units placed on the arrays;
- a wind direction sensor also similar to the ones used on the arrays;
- a u-v-w propeller type anemometer for triaxial flow measurements;
- 5 shielded, welded thermocouples at 0.75,1.5,3.0,6.0 and 8.0 m height on a mast;
- at selected sites, unshielded thermocouples at the same tower heights as the shielded units;
- a ground circle of 8 thermocouples at semi-cardinal compass points on a 10 m radius circle centered on the instrument tower.

In addition equipment for testing purposes such as the Palmer anemometer and the SAIC line path averaging system (not shown) were to be deployed as well. Unfortunately, the Palmer unit did not arrive in the field until after the fire and so could not be evaluated. The SAIC line path averaging system, while it was installed failed due to mechanical damage early the fire and hence it's performance could not be readily determined.

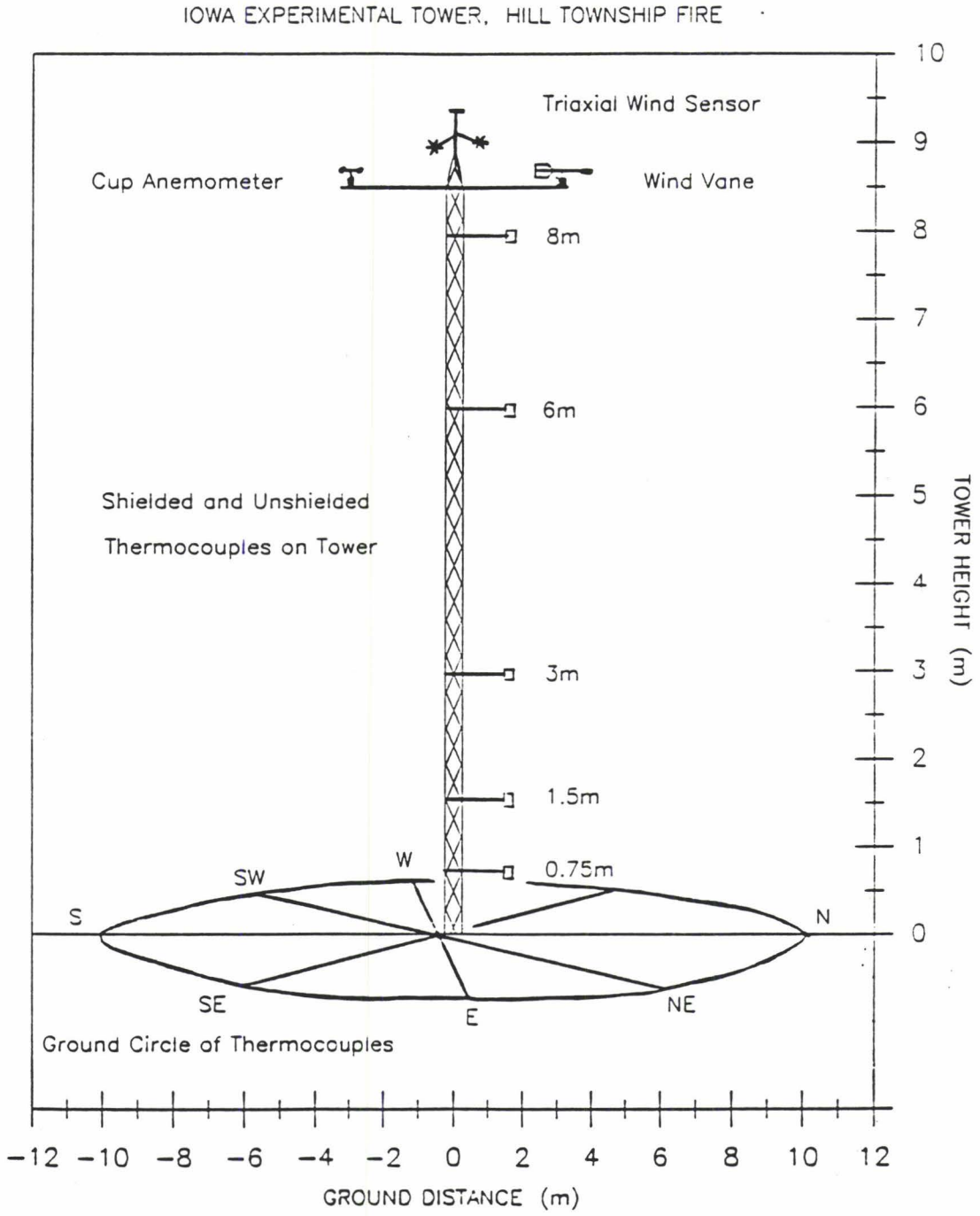


Figure 2. Instrumentation on the IOWA designed and deployed fire dynamics sites.

LIMITATIONS OF THE DATA SET

Advances in design over the 1988 effort

It would seem appropriate, before discussing the limitations in the present design and the data set which will be collected by IOWA in this project, to review briefly the changes and advances which the present design represents over last year's efforts by IOWA in the 1988 Canadian Mass Fire Program. The most significant advances are listed below.

1. It will be possible here to deploy a carefully positioned, integrated, whole fire, spatial array of towers which will enable a much better characterization of the whole fire wind field than we previously achieved.

2. The larger total number of data contributing towers will greatly increase both the data quality and data utility by allowing a much denser spatial grid. Given the high degree of local variability which has been shown to occur in the results from IOWA's research in the 1988 fires this is a very significant issue. One site does not a fire represent!

3. Based on data from last years work a new type of u-v-w will be utilized with a somewhat higher temperature performance and somewhat increased survivability. While these new units are far from ideal they do represent an improvement over the previous design (more on this later).

4. Based upon IOWA's findings from last year's effort the size of the surface temperature grid will be increased from 5 m radius (10 m diameter) to a 10 m radius (20 m diameter). This will enable more effective characterization of localized spread rates and near tower conditions.

5. Based upon last year's work a denser vertical temperature profile will be utilized to provide more detailed vertical profile data.

6. Several new types of sensors will be tested in this year's efforts.

7. A more careful effort will be made by IOWA to structure the grid and overall design to enable more effective integration of in-fire and perimeter data.

Remaining limitations of the IOWA data set

Despite the forgoing improvements in the design there remain a number of quite significant limitations in the grid design, sensors utilized and deployment which must be kept in mind when using the data.

1. The grid itself, consisting of 9 in-fire sites, would probably be more effective if it were increased to 16 sites. While 9 is adequate, the failure of a single site will have an impact on the overall flow field.

2. The instrumentation in the grid is not completely consistent. Only 5 of the sites will carry u-v-w sensors, the remainder will carry thermal anemometers for vertical flux measurements. Even if the thermal anemometers function properly (something in my view which will not be possible) their output, especially from within aluminum shields, will be very difficult to compare with the u-v-w data. The question of whether the differences in readings are the result of differences in sensors, local effects, or real variations in the flow fields in the fire will be difficult to resolve with any reasonable levels of confidence.

3. The use of either the shielded thermocouples or the unshielded thermocouples as temperature measurement strategies in the fire are both not entirely satisfactory and the errors inherent in both approaches will have to be considered further.

4. The use of point temperature measurements as opposed to small larger spatial integration also will some pose problems for the subsequent analysis.

5. It had been hoped that the u-v-w's deployed by IOWA could carry metal propellers. It was not possible however in the time between funding allocation and deployment to design and fabricate such units. Instead, it was necessary to employ an improved temperature capacity polycarbonate propeller design which resulted in an increased but clearly not wholly adequate temperature capacity in excess of 200 C (continuous). Failure of the propellers may be expected if temperatures exceed 200 C at the tower tops (10 m above the surface). This was recognized in the design and the deployment strategy. Therefore, as an interim measure, an intercomparison tehcnique has been developed (and tested) utilizing the metal cup anemometers and metal directions sensors running in parallel with the u-v-w 's. This technique will enable us to maintain data quality assurance from the u-v-w's up to the point of failure. The u-v-w's therefore will be able to operate up to failure (should some of them fail) with good reliability.

Replacement of those propeller which will fail is a relatively trivial matter (the propeller units are interchangeable and quite inexpensive costing only $25. apiece. To data, the actual signal generator and data transmitter systems or the housings of the anemometers have not failed in use in fires. Thus the maximum negative impact is: (a) the problem of replacing the essentially disposable propeller blades of the unit; and (b) the more serious matter of data lost after failure of the blades. While these limitations are clearly recognized, these u-v-w's will serve well as a stop-gap measure while IOWA's plans for the metal propeller development continues.

The ability of these units to provide high quality, vertical flux and 3-dimensional wind vector data would appear to justify their deployment even with the above obvious constraints. They may well provide the only vertical flux data we will be able to obtain in these fires. However, it is clear that more work in this crucial area of fire research is clearly needed. Therefore, in addition to working on the question of developing metal propellers, testing and evaluation of other wind sensors, such as the Palmer design will also be undertaken by IOWA.

(III) DETAILED EVALUATION OF ASPECTS OF SPREAD AND TURBULENCE ARRAY

The evaluation is divided into five parts: (A) the intent of the design; (B) the required deployment of the turbulence arrays; and (C) an assessment of the design and the subsequent performance; (D) the implications of the performance limitations and (E) recommendations.

The issues which became apparent in preparing this evaluation are significant. As will, I believe, become clear, the inherent limitations in the PSRC design, as deployed, presents major difficulties. These problems are particularly acute in terms of the use of the data to determine the in-fire: (a) turbulence; (b) simultaneous horizontal and vertical wind fluxes; and (c) heat and energy transfers to and from the surface. What makes these limitations and failures particularly unfortunate is that these shortcomings affect the very inputs which are some of the most important forcing elements for the subsequent plume development and hence are crucial inputs to the modelling efforts.

(A) Intent of the Design

It was the intent of PSRC to use the turbulence tower arrays to assess turbulence by using each of the three tower array structures as an eddy correlation device. It was also intended that the array would provide both horizontal and vertical wind and temperature flux data in order to enable both horizontal and vertical energy transfer assessment. This effort to study turbulence and energy flux required, at a minimum, the collection of simultaneous horizontal and vertical wind direction and velocity readings not only on an individual tower but from the three towers in a turbulence array. The associated heat and energy flux determinations also required temperature measurements at the same locations, preferably with a vertical sensor array with data logger clocks synchronized both with the wind measurements and also between the towers in each array.

(B) The Required Deployment of the Turbulence Arrays

As you are aware PSRC specified the turbulence array design, the equipment and the deployment pattern. Iowa, after making a number of recommendations all of which were rejected, deployed the turbulence and spread array equipment in accordance with the PSRC requests (with one exception - I refused to use soldered thermocouples and insisted on using welded thermocouples in the nine turbulence and spread array towers which Iowa deployed (as well as our own towers) -PSRC used soldered thermocouples in their three towers.

Of particular concern here are the following PSRC deployment and equipment requirements:

1) PSRC insisted on the use of Sierra thermal anemometers in aluminum shields for the measurement of the vertical wind fluxes. One of these units was operated on each of the towers in the three turbulence arrays (and also in the single spread array).

2) The horizontal winds were measured with pulse counting cup anemometers.

3) The clocks operating each of the data loggers were manually synchronized.

4) The sampling rate was every two seconds.

5) The three towers making up each turbulence array were spaced at a distance of 10 m apart in the case of one of the Iowa deployed arrays and that of the one PSRC deployed array. The third array, at the insistence of PSRC was placed with a spacing of 20 m by Iowa. All anemometers were located at a height of 10 m.

6) The temperature sensors were placed inside vertically mounted aluminium shields.

An assessment of the consequences of each of these decisions is outlined below.

(C) Assessment of the Design and Subsequent Performance

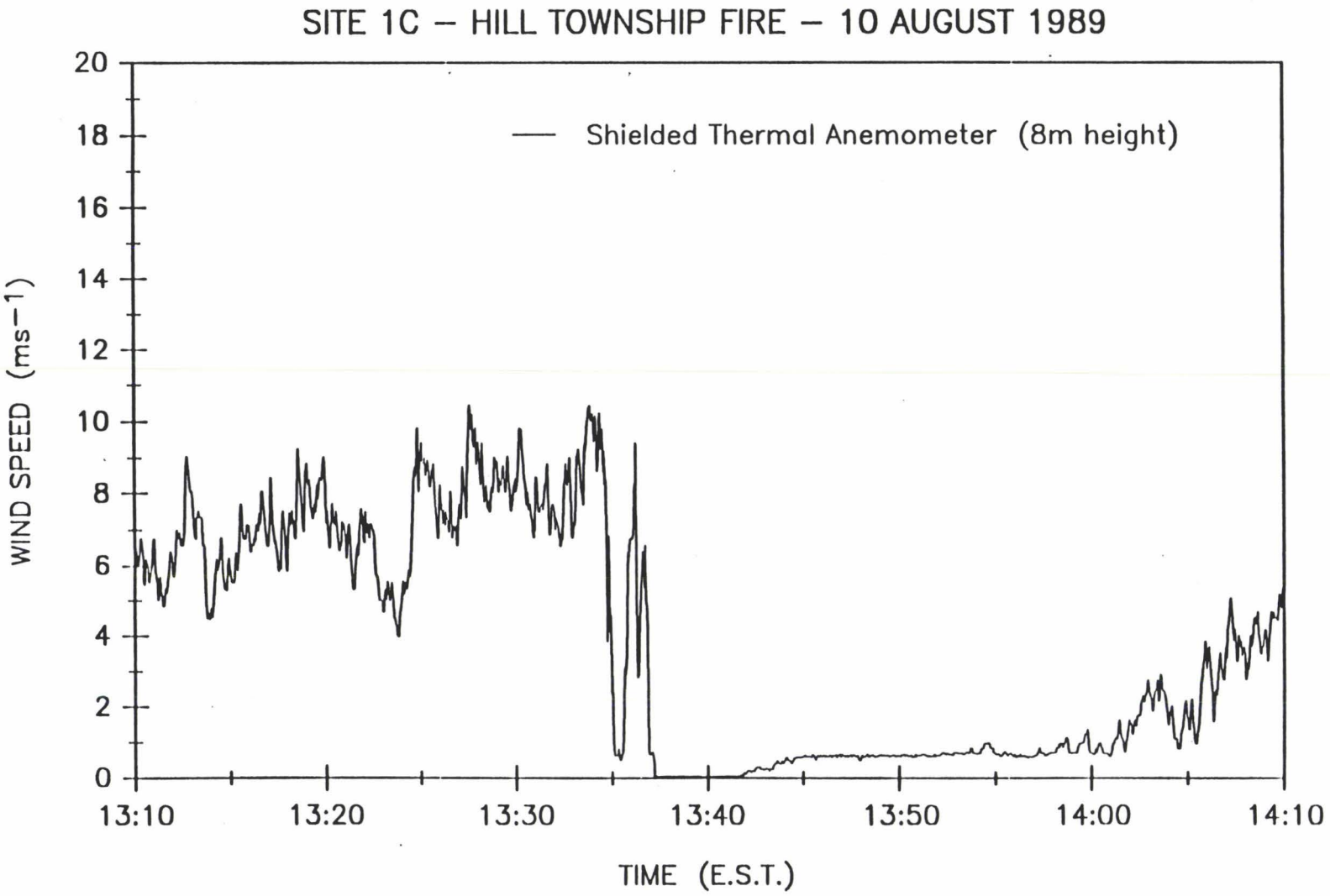
(1) The use of shielded thermal anemometers.

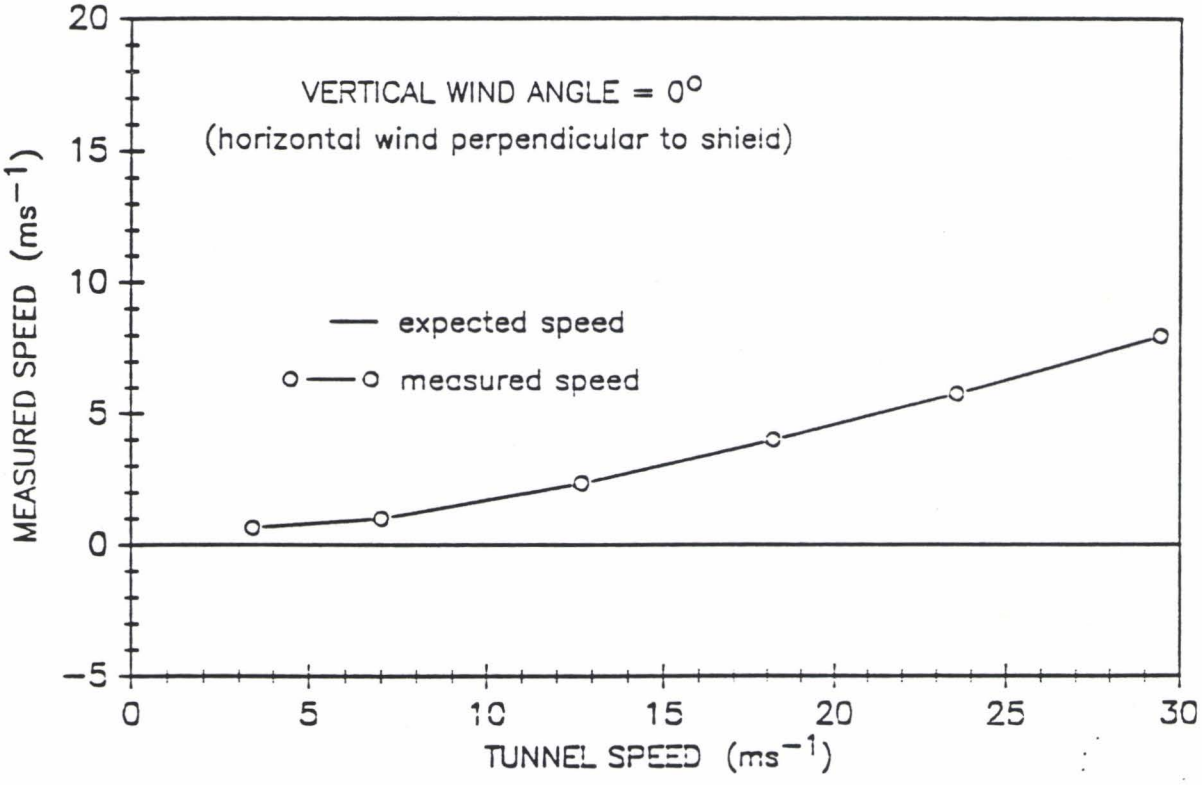
PSRC requested the use of Sierra thermal anemometers operated within a vertical aluminium shield to measure the vertical wind fluxes. While the use of thermal anemometers in more conventional environments is well established the use of a thermal anemometer in a dynamic fire environment poses serious difficulties. The most significant problem involves the inability of the anemometer to effectively compensate for rapid changes in the temperature in a fire. The thermal anemometers specified and used are inherently incapable of compensating for the rapid temperature changes taking place in the flaming front of the fire and to a lesser degree even the smoldering phase. The time constant for the thermal compensation, as stated by the manufacturer, is no better than 15 seconds while the actual velocity head which senses the velocity is much faster (on the order of 1 second). The net result, under rapidly changes air temperature conditions is that the temperature compensation is not able to keep up with or correct the velocity readings. The errors resulting moreover, are not minor. In many cases in this study the compensation errors resulting from this problem are so large that the thermal velocity sensors read 0 m/s velocity or near 0 m/s during the flaming front arrival, precisely when higher velocities were expected and in fact occurred.

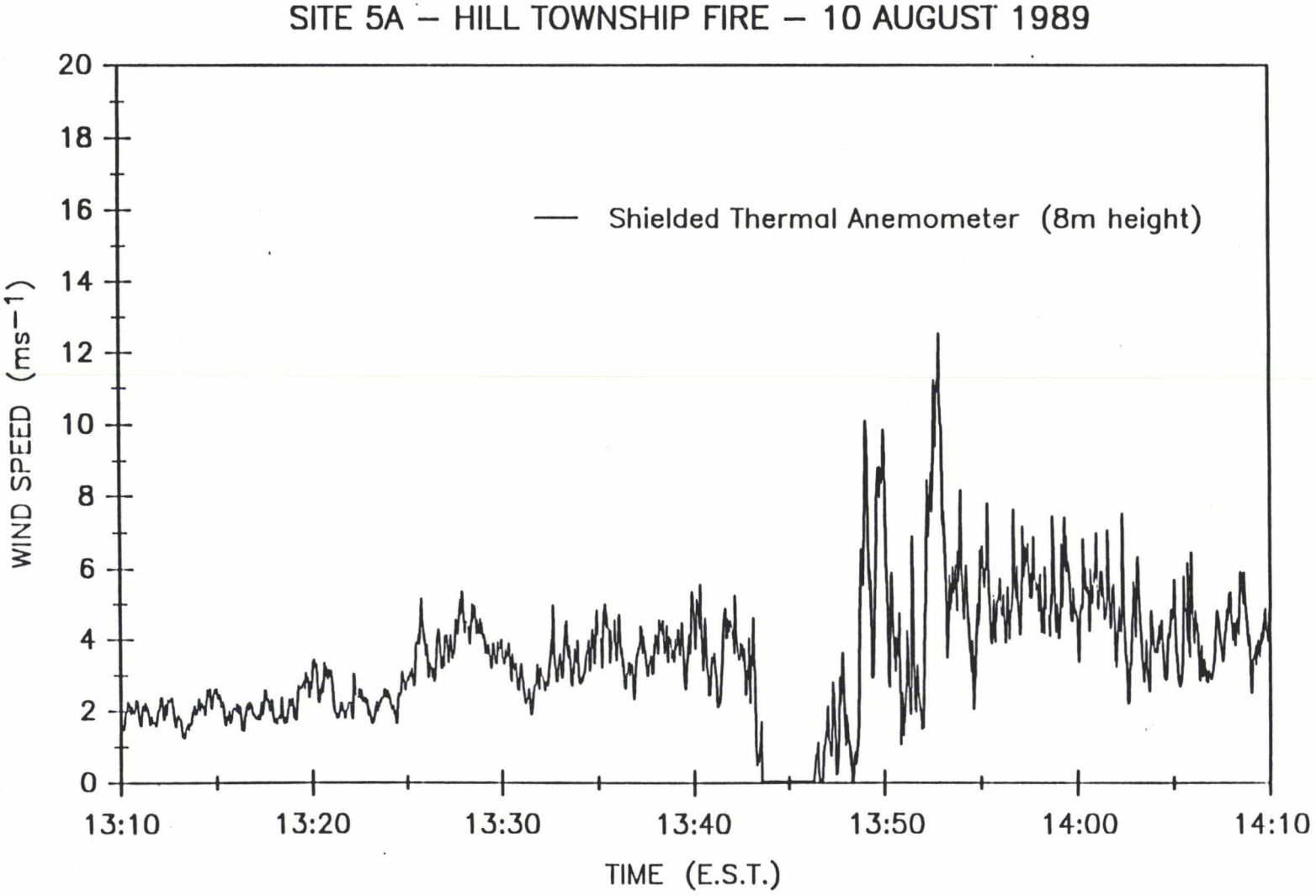
The following graph (page 4) from the thermal anemometer data collected in this summers fire illustrates the point. The thermal anemometer failed dramatically at the very height of the fire and the data subsequent to the passage of the flaming front can only be characterized as of a dubious character. The data is simply unreliable.

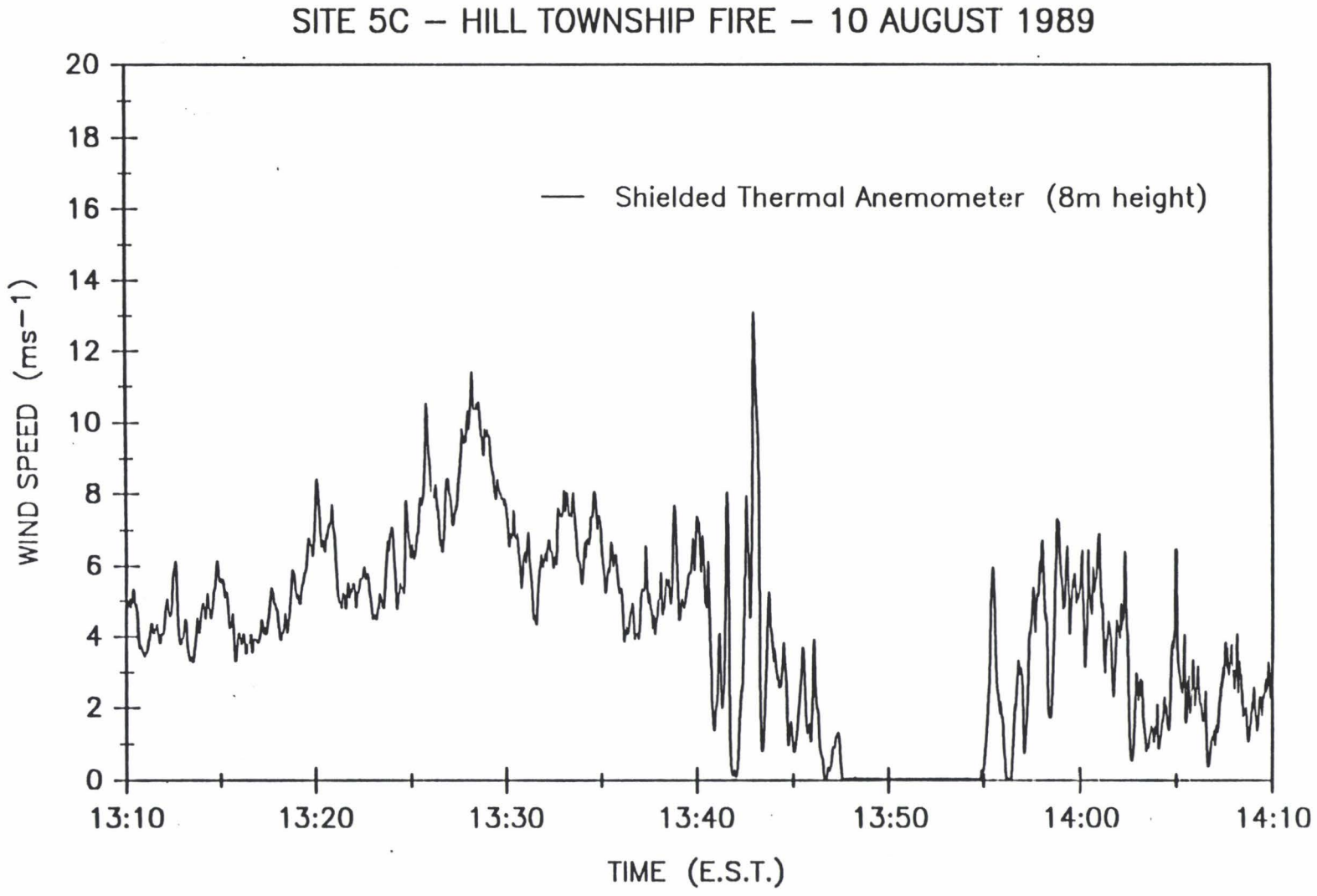
The issue is further compounded by the effects of the shields designed by PSRC to enable the thermal anemometers to be used as vertical velocity flux sensors. Post-fire wind tunnel testing of these shields (in an optimum low turbulence environment) has shown that with a pure horizontal wind (ie. no vertical component) the sensor will register the presence of a vertical wind which exceeds 20 % of the horizontal flow (see graph page 5). In other words, in a pure horizontal wind of 10 m/s with no vertical flow the thermal will register a false 2.5 m/s vertical flux when in fact there is NO vertical wind taking place at all. In terms of the fires studied this summer the actual vertical fire winds which were measured in the fire (using other sensors) indicate velocities of up to 5 m/s are common. The shields therefore would, by their interference with the air flow cause the thermal sensors to indicate, even under moderate wind conditions, vertical fluxes which would be on the order of a 50% error (and this assumes NO temperature compensation problem exists).

The combined effect of the massive temperature compensation errors and the problems caused by the aluminium shields that the data is confusing, contradictory and completely unreliable. A case in point is the data from site 5 of the Hill fire. The thermal anemometers at site 5A and 5C (see graphs attached) were not 15 m apart yet the reading they provide are not even near being in agreement.


SITE 1C – HILL TOWNSHIP FIRE – 10 AUGUST 1989
Shielded Thermal Anemometer (8m height)
WIND SPEED (ms⁻¹)
20
18
16
14
12
10
8
6
4
2
0
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)


VERTICAL WIND ANGLE = 0°
(horizontal wind perpendicular to shield)
expected speed
measured speed
MEASURED SPEED (ms⁻¹)
TUNNEL SPEED (ms⁻¹)
20
15
10
5
0
−5
0
5
10
15
20
25
30


SITE 5A – HILL TOWNSHIP FIRE – 10 AUGUST 1989
Shielded Thermal Anemometer (8m height)
WIND SPEED (ms−1)
20
18
16
14
12
10
8
6
4
2
0
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)


SITE 5C – HILL TOWNSHIP FIRE – 10 AUGUST 1989
Shielded Thermal Anemometer (8m height)
WIND SPEED (ms−1)
20
18
16
14
12
10
8
6
4
2
0
13:10
13:20
13:30
13:40
13:50
14:00
14:10
TIME (E.S.T.)

Finally, the problems associated with the thermal anemometers are further compounded by the inherent inability of the thermal anemometers to indicate whether the flow direction is up or down. Without knowledge of the vertical flux direction as well as the vertical flux magnitude it becomes very difficult to determine any reasonable heat or energy flux pattern.

For all practical purposes, the PSRC designed system of using Sierra thermal anemometers, operated within vertically mounted aluminium shields, as vertical fire wind sensors failed completely.

2) The use of pulse counting cup anemometers to measure the horizontal winds.

The use of pulse counting cup anemometers is a well established and standard technique in meteorology and hydrometeorology. The use of a variety of designs of pulse counting cup designs in fire has also been a common practice (a number of designs such as the Palmer type and other have been used over the years). The difficulty which arises with the use of pulse counters in this application centers on the specific application itself. The pulse counters specified by PSRC operate on a 2 count per revolution basis and in this application were scanned every 2 seconds. The combination of the pulse signal and the scan rate means that these units were operating in the fire as horizontal wind averaging systems. They totalized the counts over a two second period and then the average velocity over that period was calculated. When combined with the horizontal direction sensors (operated in parallel with them) these cup units can provide a good general indication of the broader fluxes in the horizontal wind field.

However, when deployed in a turbulence array as was the case here, problems arise. The response time of these units is not particularly fast for turbulence work and their use in an averaging mode which is so slow presents difficulties. The fire environment is an extremely dynamic one in which rapid wind shifts and fluxes are common. It would not be uncommon,for example for a gust to sweep past a point such that a horizontal wind of 10 m/s would increase to 20 m/s in a 2 second period. Assuming, for example, a gust hits the array half way between scans and an instantaneous response time (obviously not the case) the cup would register this as an increase from 10 to 15 m/s for this period. It would miss the peak value of 20 m/s and also only be able to determine the arrival of the wind gust itself to within a 2 second time frame.

With the towers in each array only 10 and in one case only 20 meters apart this means the arrival of a gust at each tower is only approximate within a 2 second window. For eddy correlation analysis on a three point tower array with winds in the 10 - 30 m/s range this is simply not an acceptable variability. Turbulence and the associated correlation analysis over short distances requires much higher accuracy in terms of when fluxes occur and the magnitude of those fluxes. Eddy correlation analysis with relatively long time base averaged wind data is a contradiction in terms.

3) The clocks operating each of the data loggers were manually synchronized.

PSRC decided that manually synchronizing the clocks between the data loggers in the turbulence arrays would be adequate for their purposes. Hence ALL loggers in the arrays were manually synchronized. Manual synchronization resulted in time bases which were generally within 0.5 seconds of one another. A 0.5 second error is, in and of itself not a major concern, if one is comparing data from towers spaced at some distance from one another (on the order of a hundred or several hundred meters) and when dealing with winds on the order of 10 -30 or even 40 m/s.

Unfortunately such a variability is quite significant for measurements taken when comparison of data from towers only 10 or 20 meters apart is being made. If a gust of wind strikes one tower at 0.0 seconds and strikes a different tower in the array 0.75, 1.0, or 1.5 seconds later the impact on the correlation and turbulence analysis is to say the least significant. The fact that the readings (as indicated above) are 2 second average values further complicates the matter. Determining turbulent transfers under such a combination of variabilities between time bases and only relatively broad, wide band, average velocity data on a such a spatial (10 m or 20 m) seems doomed to failure. Their are simply too many uncertainties. Even if some type of rough determination of turbulent activity can be extracted the credibility of the results will be low at best.

4) The sampling rate was every two seconds.

The selection of the two second sampling rate by PSRC for the turbulence and spread arrays, while acceptable for the general wind conditions in the fire, poses major problems for the arrays. Most turbulence studies and eddy correlation studies on such a basically micrometeorological scale, require sampling rates at least an order of magnitude or even two orders of magnitude higher speed (0.2 down to 0.02 or 0.01 seconds between scans between scans) in order to enable the correlations to be effective. A 20 m/s gust would only take 0.5 seconds to sweep through an entire PSRC turbulence array and would likely register essentially simultaneously on all three towers. Recall as well that the readings are only 2 second average values not instantaneous values taken at 2 seconds. The ability to separate out the gusts penetration and passage through an array would require much faster readings. Conventional measurement practice would suggest a scan rate at least an order of magnitude and preferably 2 orders of magnitude faster than the flux rate of the phenomenon (in this case the turbulent fluxes).

Finally, the fact that the time bases were not electronically synchronized, but were only manually coordinated for the data loggers at each tower (see (3) above) means that the readings were not take at the same time. Any effort to compare the results between the towers must also come to terms with this limitation.

5) The horizontal spacing for the arrays was not uniform. Two of the arrays (the one deployed by PSRC and one of the arrays deployed by Iowa) were spaced at 10 m while a third array, deployed by Iowa was at 20 m spacing.

Comparing the results between the different arrays (ie. to study eddy size effects and select an optimal array spacing) would be challenging under the best of circumstance since each array was located at quite different positions in the fire and in different topographic settings and the significance of location and topography would have to be taken into account. The problems arising from items (2), (3) and (4) above make undertaking such an effort of questionable value. There are simply too many difficulties with the data. Any effect of varying the horizontal spacing will likely be lost in all of the other uncertainties associated with this array data. In fact, this variability in the spacing introduces one more uncertainty into the turbulence array data sets - a further complication.

Finally, the complete failure of the 10 meter spacing array which PSRC itself deployed to collect ANY horizontal wind velocity data in either of the fires this past summer (a failure due to the selection of the wrong type of signal cable by PSRC) means we only have data from the one 10 m and one 20 m array which Iowa deployed following the PSRC design and deployment requirements (but using Iowa's own wiring technology) - This makes a bad situation only worse.

The net result of PSRC's design and operational decisions and requirements as outlined in items (2), (3), (4) and (5) above and the complete failure of the one array they deployed to collect any horizontal wind velocity data is the introduction of such a high level of uncertainty into the turbulence array horizontal wind data that the likelihood of carrying out useful and credible analysis of the turbulence and the horizontal wind fluxes (in terms of eddy correlation etc) is small at best. Combined with the failure of the vertical flux sensors (ie. the thermal anemometers discussed in (1) above) the effort to carry out such an analysis is simply not viable.

6) The temperature sensors were placed inside vertically mounted aluminum shields.

PSRC, in an effort to minimize the effect of radiative heating of the thermocouples, required the thermocouples to be placed inside a vertically mounted 2 inch diameter aluminium shield. The aluminium shields were of PSRC's design and specification. In the case of the three towers (making up one array which they instrumented themselves) PSRC insisted on using soldered, large diameter, twisted, thermocouples. In the case of the remaining arrays and all of the other towers which Iowa instrumented small bead, low angle butt welded thermocouples were employed. In the case of all of the arrays, at PSRC's insistence, the shields were used. Three of the aluminium shields melted outright. The effect of the unmelted shields on the remaining thermocouples is still not fully determined. Preliminary analysis of the data from other sensors which Iowa deployed on it's own towers suggest the shields may have caused up to a 100 C error in the observed temperatures. While some capacity to correct for this error does exist it will likely require a fairly wide error band being placed around much of the array temperature data. Comparison with temperature data will have to be undertaken with some caution.

D) Implications of the Performance Limitations

The implications of the above limitations on the data are the following:

1) the failure of the thermal anemometers as vertical wind flux sensors in the arrays means assessing the turbulence and the vertical heat and energy fluxes will be difficult;

2) the horizontal wind systems in the PSRC turbulence arrays are, as they were deployed, NOT adequate to provide the data needed for a proper and credible turbulence or eddy analysis;

3) the combined thermal anemometer and horizontal wind sensor deficiencies would rule out the turbulence arrays as presently designed for detailed in- fire wind analysis or three dimensional assessment of the fire wind processes;

4) each of the turbulence arrays may be used as a single point on a whole fire grid to contribute to the overall fire wind field. As general wind velocity indicators the horizontal cup anemometer data is basically sound. If used in this way the 2 turbulence array and 1 spread array sites, when combined with the separate 5 site Iowa tower system, should provide, as has already been shown at the Missoula meetings, a reasonable assessment of the general fire wind activity. The complete failure of the horizontal wind velocity measurements and the unreliability of the vertical wind data collection attempted direclty PSRC in the single turbulence array they deployed rules out the use of the velocity data they collected in the overall wind field analysis.

E) Recommendations

Based upon the above information and related analysis which is presently underway I would make the following recommendations:

1) that at the minimum the data from the turbulence arrays be used with extreme caution for any type of detailed in-fire analysis such as turbulence which might be attempted. In fact, I would suggest it may simply not be worth the effort and that the data might well be put aside and not used for that purpose at all.

2) that given the apparent failure of the PSRC turbulence array design, as deployed, it not be used again. If it is to be attempted again the turbulence measurement issue should be undertaken with a new or at minimum complete reassessment of the design.

APPENDIX III

RESULTS OF THE HILL TOWNSHIP PRESCRIBED BURN:

OBJECTIVE K - GIS INTEGRATION

OVERVIEW

The results presented here relate to objective K, the final objective oultined in the amended agreement and study plan. Objective K related to:

K. The use of a GIS as a method of integrating the available data, particularily the wind and terrain data. This integration of data layers was to then be utilized to create an animated video of the primary burn period of the fire.

The material presented in the following section of this final report integrates the wind speed and direction data from within and in the perimeter areas of the fire, the terrain data and other relevant materials. This integrate data was then processed to generate image files which formed the basis of first a preliminary and then a final version of the animation of the integrated in-fire perimeter wind flow fields active during the main burn period from 13:10 - 14:10 on the day of the fire. The actual data and image files are provided on two media and in ASCII format for ease of access. Copies of the animation videos are also provided. (Other materials such as in-fire videos etc. were provided with previous reports).

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INTEGRATED SUMMARY WIND SPEED DATA FOR THE IN-FIRE AND PERIMETER TOWERS

The basic wind speed data for the horizontal in-fire, perimeter and ambient wind field analysis came from the in-fire anemometers deployed by the University of Iowa and Forestry Canada. The anemometer systems directly deployed by Pacific Sierra Research Corporation completely failed. The U.S. Forest Service did not provide their data.

The data summarized on the following two pages represents the basic mean horizontal velocity at 1 minute increments for the period of 13:10 - 14:10 EST (the main burning period of the fire) on August 10, 1989. The tower locations are indicated on the horizontal axis in the table. Ground locations are indicated in Appendix I and II and in the "Canada Mass Fire Experiment,1989" (NISTIR REPORT 4444) and are indicated in the flow field video provided with this report. All wind speed data values are provided in meters/sec. This data is also contained in the data files contained on the floppy discs and the 1/4 in magnetic tape.

The data presented form the basis of the development of the flow field mapping. The use of the one minute increment was necessitated by the sample rate of the perimeter towers (1 minute). The higher density sampling rates (2 second and 5 second) utilized on the in-fire towers provide more detailed data but the integration of the entire tower array required a common time base data set for the purposes of preparing a broad overview visualization of the flow field dynamics.

It should be noted that the more detailed graphing of individual anemometer data is presented in Appendix I and II.

hr-min	minute	a-sp	b-sp	c-sp	d-sp	e-sp	1c-sp	2x-sp	3c-sp	4x-sp	5c-sp	8x-sp	9x-sp
1310	0	4.29	3.30	4.53	3.02	2.88	4.85	4.73	4.44	4.22	3.96	4.59	4.62
1311	1	5.19	3.75	3.68	4.66	2.67	4.13	5.04	5.06	4.03	4.22	4.16	4.84
1312	2	4.54	3.87	3.21	3.76	3.70	6.46	3.87	4.48	4.42	5.09	4.46	3.90
1313	3	4.84	3.98	3.21	3.20	3.17	5.56	6.51	5.85	4.06	4.72	6.17	4.30
1314	4	3.17	3.29	3.75	3.81	2.56	4.41	5.05	5.26	6.52	5.31	4.55	5.31
1315	5	3.64	3.87	3.10	4.77	4.11	5.16	4.89	5.35	5.04	5.00	5.09	4.21
1316	6	4.27	4.03	3.43	3.47	3.21	5.66	6.25	7.16	5.15	4.84	5.01	4.67
1317	7	4.25	3.27	4.20	3.62	3.80	5.48	6.45	6.77	4.65	4.65	5.19	4.89
1318	8	4.59	2.60	4.40	2.64	4.90	5.48	6.33	6.46	5.55	4.75	4.61	5.68
1319	9	3.10	1.99	4.14	3.08	4.74	5.58	6.55	7.93	5.28	6.54	5.63	4.07
1320	10	3.42	2.51	3.16	4.13	3.83	5.32	7.03	7.02	5.33	7.66	5.85	4.51
1321	11	4.48	4.99	3.18	3.35	3.61	5.14	7.34	7.46	5.89	5.90	4.21	5.16
1322	12	3.90	4.55	5.48	2.20	3.34	5.74	6.07	5.60	5.91	5.45	5.65	8.02
1323	13	3.91	5.13	3.70	3.53	3.57	3.99	6.02	5.88	5.12	5.72	5.07	8.03
1324	14	5.02	4.99	4.49	3.05	3.87	5.33	7.18	6.35	6.33	5.79	4.14	8.04
1325	15	3.56	3.04	4.97	4.86	5.44	6.89	9.31	9.03	8.95	6.84	7.05	9.39
1326	16	4.70	4.66	4.56	4.33	4.64	5.76	9.27	11.58	9.35	6.82	6.61	10.52
1327	17	3.90	4.36	4.30	3.16	4.35	7.24	9.37	12.69	10.09	8.10	6.79	11.17
1328	18	3.49	3.31	4.27	3.34	3.30	6.36	10.76	12.55	11.56	9.84	7.68	11.64
1329	19	4.31	2.91	4.42	3.93	3.60	6.14	12.41	11.42	11.23	9.61	7.70	11.87
1330	20	3.35	2.29	5.92	3.26	3.62	6.48	11.31	10.25	10.38	8.01	7.41	12.08
1331	21	3.83	2.48	2.92	3.82	3.51	6.64	10.50	9.57	9.57	7.15	7.39	10.45
1332	22	4.51	4.07	2.08	2.83	3.35	5.95	11.34	9.67	7.72	7.30	6.19	10.45
1333	23	3.73	2.60	3.30	2.65	2.85	7.42	11.54	10.29	8.93	7.63	7.25	12.12
1334	24	4.72	2.96	3.13	2.64	2.63	8.80	11.05	9.61	9.03	8.39	7.15	10.88
1335	25	4.20	4.60	3.35	2.71	2.47	8.88	11.64	10.88	10.93	8.40	8.50	11.15
1336	26	4.01	3.25	4.75	3.98	3.47	9.07	11.40	11.34	10.22	8.38	8.62	12.15
1337	27	3.53	3.17	4.11	2.68	3.09	9.07	12.22	11.63	11.42	9.01	10.51	10.05
1338	28	3.32	2.80	3.69	2.96	4.24	8.21	11.60	12.45	13.55	10.17	9.73	10.14
1339	29	5.47	2.43	3.74	2.60	3.78	9.00	11.71	12.81	12.48	9.26	9.88	8.54
1340	30	4.09	2.67	3.31	2.10	3.75	9.52	14.37	12.45	11.79	10.24	12.89	11.19
1341	31	3.23	3.79	3.09	4.12	3.79	7.88	13.55	11.10	10.45	11.05	11.86	10.07
1342	32	3.27	3.60	5.02	2.77	4.54	7.68	12.86	10.83	10.87	11.26	11.26	8.74
1343	33	3.41	4.18	4.84	4.36	4.14	7.41	12.92	11.57	11.84	11.22	11.50	9.70
1344	34	2.28	3.18	3.71	3.46	3.09	7.79	13.19	13.14	11.65	10.11	11.20	10.59
1345	35	2.93	2.89	4.13	3.27	2.19	9.19	11.56	11.66	11.37	10.45	11.50	9.70
1346	36	2.89	3.35	3.65	3.43	2.40	8.44	11.85	11.67	10.84	10.40	10.60	9.91
1347	37	4.13	3.01	3.04	2.56	3.30	8.56	11.57	11.85	10.01	9.52	10.28	9.82
1348	38	3.99	3.90	3.57	2.25	2.74	8.97	11.65	11.68	10.16	11.44	10.42	9.54
1349	39	4.32	3.89	4.13	2.71	4.52	10.96	13.22	12.19	11.17	11.23	11.23	9.61
1350	40	3.83	4.18	4.02	2.47	3.35	11.35	13.76	12.64	11.56	11.71	11.22	11.32
1351	41	4.97	4.52	3.14	3.37	3.77	8.94	11.37	11.32	10.65	11.27	9.96	12.12
1352	42	3.57	3.12	2.91	3.55	3.47	9.57	10.24	9.50	10.78	11.09	10.56	8.66
1353	43	3.74	3.09	3.69	3.70	3.67	9.31	10.18	8.49	8.14	9.37	10.67	8.13
1354	44	3.75	3.42	3.67	3.40	3.73	8.61	10.01	10.44	8.93	10.16	8.26	8.11
1355	45	4.67	3.46	3.12	3.03	4.06	10.55	11.54	10.64	9.52	8.83	8.89	9.18
1356	46	3.76	4.83	3.87	2.44	3.44	11.50	11.79	10.87	10.59	10.55	9.23	9.37
1357	47	2.74	3.37	4.63	4.30	3.24	11.76	11.43	10.30	10.48	10.65	10.33	8.47
1358	48	2.67	2.10	3.82	4.91	3.11	11.12	10.85	9.90	8.79	9.07	9.60	8.88

1359	49	3.50	3.25	3.79	3.58	3.91	10.15	10.30	9.45	9.09	10.04	9.33	8.85
1400	50	4.55	3.31	4.37	4.30	4.44	8.36	9.83	9.43	9.02	9.01	7.57	8.85
1401	51	5.06	5.36	2.91	3.07	2.84	10.59	10.95	10.28	8.59	9.98	7.69	8.93
1402	52	3.72	5.02	4.29	3.64	3.75	11.06	10.78	9.39	9.03	9.85	9.63	10.06
1403	53	4.73	3.64	3.54	3.92	4.33	10.27	10.83	9.05	8.24	8.31	9.57	9.25
1404	54	5.14	4.81	3.86	4.28	4.17	10.25	10.44	9.59	8.89	10.36	8.18	9.49
1405	55	3.96	3.54	5.61	3.75	4.20	10.83	10.13	8.58	7.92	7.67	7.02	8.71
1406	56	3.61	3.97	3.93	3.46	4.21	10.41	10.30	9.56	6.24	6.63	8.54	9.76
1407	57	3.54	3.03	4.03	4.93	5.26	10.79	9.64	9.52	9.12	9.19	9.71	9.45
1408	58	2.86	4.18	3.95	4.09	5.59	11.07	9.41	8.68	9.63	9.34	9.39	8.52
1409	59	4.68	3.55	5.37	3.72	4.17	12.23	9.82	9.88	8.55	9.57	9.41	8.41

INTEGRATED SUMMARY WIND DIRECTION DATA FOR THE IN-FIRE AND PERIMETER TOWERS

The basic wind direction data for the horizontal in-fire, perimeter and ambient wind field analysis came from the in-fire sensors deployed by the University of Iowa and Forestry Canada. Pacific Sierra Research Corporation failed to provide any wind direction data for the integration effort. The U.S. Forest Service did not provide their data.

The data summarized on the following two pages represents the basic mean horizontal direction at 1 minute increments for the period of 13:10 -14:10 EST (the main burning period of the fire) on August 10, 1989. The tower locations are indicated on the horizontal axis of the table. Ground locations are indicated in Appendix I and II and in the "Canada Mass Fire Experiment,1989" (NISTIR REPORT 4444) and are indicated in the flow field video provided with this report. All wind direction values are provided in degrees. This data is also contained in the data files contained on the floppy discs and the 1/4 in magnetic tape.

The data presented form the basis of the development of the flow field mapping. The use of the one minute increment was necessitated by the sample rate of the perimeter towers (1 minute). The higher density sampling rates (2 second and 5 second) utilized on the in-fire towers provide more detailed data but the integration of the entire tower array required a common time base data set for the purposes of preparing a broad overview visualization of the flow field dynamics.

It should be noted that the more detailed graphing of individual wind direction is contained in Appendix I and II.

hr-min	a-dir	b-dir	c-dir	d-dir	e-dir	1c-dir	2x-dir	3c-dir	4x-dir	5c-dir	8x-dir	9x-dir
1310	271.0	250.7	265.0	244.9	259.7	252.07	254.59	250.80	247.59	276.16	258.64	287.50
1311	264.4	272.7	255.8	227.2	268.8	251.99	258.20	274.36	257.84	275.31	240.28	299.33
1312	268.1	279.6	244.8	222.6	274.2	260.21	288.88	276.80	272.18	277.71	248.98	304.56
1313	268.8	292.7	279.7	229.8	288.0	278.91	272.88	268.76	273.43	282.71	264.80	287.75
1314	293.0	275.9	286.3	245.6	268.3	273.16	262.02	244.63	246.45	272.04	277.24	288.84
1315	306.0	296.7	283.2	257.8	288.1	266.03	271.60	247.77	237.05	250.79	267.44	288.65
1316	294.2	297.5	276.3	267.6	280.0	262.19	287.75	254.92	259.45	258.07	254.70	285.61
1317	302.3	257.9	291.1	274.0	293.6	273.71	277.42	247.58	248.65	255.53	261.30	287.43
1318	299.5	237.3	271.8	264.8	289.5	264.80	277.58	269.36	260.98	274.17	259.07	292.69
1319	304.7	261.6	266.9	268.6	290.8	250.00	293.58	275.68	270.33	286.77	255.16	278.29
1320	301.3	274.9	244.7	238.6	271.9	259.20	300.33	282.44	276.94	284.60	242.90	270.62
1321	286.7	282.8	240.3	232.1	276.8	272.04	297.73	281.87	277.35	280.08	247.93	271.88
1322	276.6	283.4	259.3	227.7	288.7	281.48	296.93	272.18	266.31	267.94	265.48	269.16
1323	270.6	276.5	258.7	247.9	289.0	285.68	294.12	283.05	286.69	281.62	271.93	274.77
1324	271.3	266.3	283.9	234.8	288.0	272.00	302.96	279.83	293.55	294.74	267.99	246.54
1325	293.8	280.6	273.1	252.3	284.8	267.88	306.03	295.58	301.24	308.92	259.45	266.79
1326	295.2	270.1	274.1	252.7	280.1	278.79	288.77	286.93	299.13	305.27	268.35	266.84
1327	289.6	289.9	263.7	256.0	277.8	275.74	283.37	282.18	295.45	309.92	265.02	260.59
1328	275.9	279.3	290.9	273.0	275.3	261.73	277.53	278.38	294.25	300.65	261.54	274.22
1329	296.6	272.6	269.6	264.6	287.4	263.48	301.72	267.92	275.10	291.25	249.64	264.17
1330	301.8	274.8	271.5	254.7	283.9	252.14	297.53	270.46	278.45	279.15	246.95	259.97
1331	303.6	292.3	278.8	277.6	268.0	259.72	291.82	278.56	287.98	285.97	255.21	273.91
1332	295.1	298.8	280.3	281.2	259.3	264.62	278.88	284.38	300.09	303.37	256.82	276.39
1333	306.6	271.1	277.4	271.6	257.0	263.32	273.40	270.12	306.11	302.73	252.15	259.77
1334	303.8	287.4	280.9	276.4	252.3	259.98	278.32	265.57	283.30	308.38	247.88	266.74
1335	289.2	310.0	269.6	274.9	296.8	276.25	284.09	284.58	285.42	302.58	255.39	294.43
1336	299.2	294.3	267.6	272.7	289.8	271.74	274.68	273.48	297.80	281.38	242.28	278.59
1337	311.4	276.7	267.5	296.3	299.6	263.83	276.93	270.76	267.71	300.79	251.43	266.52
1338	301.4	276.3	254.5	288.9	294.1	264.49	295.59	285.76	303.68	299.66	265.82	280.84
1339	292.6	253.3	247.9	275.7	287.8	247.99	282.66	283.39	319.02	302.28	269.44	274.60
1340	290.0	281.9	244.5	268.0	290.5	271.14	285.21	286.28	324.87	306.50	264.67	283.56
1341	288.9	279.2	259.0	260.4	274.9	278.89	290.23	274.67	310.38	307.15	273.71	230.37
1342	287.0	272.2	273.7	251.9	267.4	271.09	289.13	270.90	306.19	297.20	260.77	259.39
1343	270.0	264.6	268.9	263.6	269.2	265.81	292.61	283.00	301.67	302.12	262.97	253.31
1344	253.9	281.5	251.4	269.2	262.4	267.10	280.68	307.65	327.65	297.16	250.43	275.03
1345	306.0	243.6	292.3	231.9	233.3	252.65	295.38	273.95	317.49	301.26	244.89	286.89
1346	312.0	242.8	274.2	231.6	264.3	250.07	275.43	275.55	315.40	300.43	247.16	286.79
1347	296.8	267.0	261.9	236.7	267.1	248.09	269.53	253.03	314.09	305.25	241.98	298.75
1348	289.3	294.8	244.8	244.7	304.6	278.70	258.19	255.02	299.19	296.89	258.90	306.09
1349	294.8	299.4	268.5	244.4	283.2	289.03	289.19	279.73	316.69	311.13	274.67	304.45
1350	302.4	302.4	299.6	261.1	250.7	272.31	299.31	286.07	313.98	286.05	257.60	256.24
1351	298.2	303.5	294.3	258.8	246.2	280.28	279.27	291.62	289.20	285.39	280.68	269.95
1352	303.3	306.9	289.7	259.1	258.6	279.01	275.95	252.92	319.26	312.25	264.43	275.80
1353	314.0	311.4	308.0	265.3	263.6	254.54	288.34	259.35	311.94	294.30	251.81	262.48
1354	313.8	286.1	312.3	270.8	287.7	242.46	296.83	278.43	318.36	283.94	239.65	286.19
1355	311.0	277.2	268.7	277.8	292.0	257.34	299.90	274.95	312.81	288.13	256.00	245.09
1356	262.8	276.4	273.1	267.2	300.4	291.50	297.06	282.79	280.17	294.71	281.27	247.73
1357	259.8	294.3	299.4	251.8	277.9	302.17	288.53	278.16	293.81	289.92	318.28	251.08
1358	279.4	263.3	287.6	235.8	278.8	310.74	288.77	272.72	294.25	291.02	312.13	264.34

1359	303.6	247.0	257.8	252.2	294.6	282.13	315.69	274.83	276.60	293.48	303.43	254.08
1400	297.3	265.5	240.1	236.6	298.1	262.98	290.93	289.23	284.32	292.65	279.83	262.44
1401	316.3	289.6	243.8	228.9	294.0	266.40	306.25	288.72	264.08	295.79	285.34	254.55
1402	300.7	282.9	265.5	230.1	307.2	304.39	300.88	278.37	264.52	293.32	302.77	249.16
1403	298.4	282.9	282.3	285.6	294.3	305.17	301.85	284.23	271.36	281.19	312.72	247.61
1404	298.1	283.6	269.2	275.9	272.5	257.88	305.74	282.08	293.49	288.15	272.42	248.69
1405	281.9	291.0	271.4	278.8	278.5	264.65	293.88	293.99	283.59	286.78	275.34	235.92
1406	288.4	290.7	287.7	268.4	285.1	281.76	288.61	284.27	292.12	284.95	287.38	258.11
1407	300.8	274.5	270.6	238.6	298.4	277.59	276.38	281.09	276.27	320.33	295.43	273.65
1408	287.6	283.8	264.1	250.3	290.8	307.74	277.50	259.99	289.18	307.64	288.14	283.16
1409	271.4	300.9	273.9	273.1	278.2	312.46	286.74	271.97	275.55	295.05	304.66	277.01

INTEGRATED TERRAIN DATA FOR THE SITE

The terrain data for the site was provided by the US Forest Service whose responsibility it was to provide be basic terrain base map. The data was provided in digital form. A copy of the terrain digital data set is included in the floppy disk set and the 1/4 in. tape accompanying this report.

The lack of ground control greatly limited the quality of the terrain map produced. This also presented serious problems for the GIS integration effort. The poor spatial horizontal and vertical resolution made registry difficult. Attempts to use a number of interpolation algorithms contained in several GIS packages (such as ARCINFO) met with limted success.

Despite the above limitations we were able ultimately, after much time and effort had been expended, to produce an approximate digital terrain base map for the integration effort. It is this terrain base which is presented in the visualization accompanying this report.

PRIMARY, INTEGRATED, WIND IMAGE DATA FOR THE FIRE

The wind field data (speed and directions) for each of the sensors in the entire sensor grid (discussed in Appendix I and II with specific locations indicated in the video terrain grid) were transfered to a registered terrain -image file base. An interpolation routine chosen (from several different algorithms tested) involving the use of Krigging was used to develop individual image wind field mappings on a frame by frame basis. Between frame integration was also employed to generate the 1800 image frames necessary for the video visualization of the wind flow field. Initially the data integration, because of computational CPU requirements, was carried out using the Illinois Cray Supercomputer Facility. The subsequent of acquisition of high end workstations in my laboratories, in conjunction with the faclities of the University Image Analysis Facility here at Iowa enable the work to be completed in-house.

The size of the image files (each file is in excess of 250 K) and the number (ultimately 1800 needed) for the visualization necessitates considerable storage. The basic data image files incorporated with this report and provided on both the floppy discs and the 1/4 in. tape are in ASCII format to enable ease of transfer. The files, which form the base of the wind field visualization, cover the one hour period of 13:10 - 14:10 and are in 1 minute increments. They are numbered in sequence on the floppies and in the file index of the 1/4 in. tape. No data compression was employed in order to ensure ease of transfer and adaptability to different machines.

PRELIMINARY VERSION OF THE INTEGRATED ANIMATION OF THE TERRAIN AND WIND FIELD DATA: TAPE 1.

The preliminary version of the integrated wind field/terrain visualization is presented on Tape 1. It consists of an overview of the terrain using a color coded topographic mapping. The view then switches to a black and white shaded image of the terrain to provide a backdrop to the wind field. The view is then rotated to enable a better view. The wind field presented covers the full 1 hour period (13:10 - 14:10) and initially shows the wind direction and wind speed variation with two cycles. The images are then repeated without the direction vectors in order to enable a better view of the overall flow dynamics.

The relatively poor quality of the imagery prompted a search for more effective visualization tools. The result is discussed in the following section.

FINAL VERSION OF THE INTEGRATED TERRAIN AND WIND FIELD VISUALIZATION: TAPE 2

The poor quality of the preliminary integrated which was developed prompted a search for ways to improve the quality of both the integration and the visualization. After some effort we were able to obtain and use (in conjunction with our Image Analysis Facility), ALIAS, a $250,000 visualization package. The use of new refinements in ARCINFO, ALIAS and the new workstations enabled the reintegration of the basic data sets and the development of the visualization presented in the video on Tape 2. Much of this new visualization is self-explanatory. It provides much better detail, rendering quality and overall is a much more useful product.

As in the case of the preliminary visualization (Tape 1), the one hour of data (13:10 - 14:10) constituting the main wind and fire activity is repeated twice in the presentation sequence of Tape 2.

In the future, the inclusion of digital IR data from the IR scanning system should prove a relatively simple process (provided adequate data and image registry, and improved digital terrain data is attained).

The addition of further data layers to the above basic GIS integrated information base, when they become available, should prove a relatively simple matter for this fire and for future fires as well.

As a final note, it is clear from viewing the visualization that the whole wind field integration provides unique insights into the overall fire dynamics, the apparent oscillation in the wind field noted in the visualization is not readily apparent in reviewing individual sensor records. Other such whole fire dynamics should emerge with the further application of this GIS based integration and visualization strategy.

What is presented here is the information which was available at the time of the completion of this report.